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FINAL SCIENTIFIC REPORT

POLARIMETRIC STUDY OF THE PLANET MARS

by

Audouin DOLLFUS

and

John H. FOCAS

Observatoire de Paris  
Section d'Astrophysique, 92 - Meudon - FRANCE

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FINAL REPORT ON CONTRACT AF-61(052)-508

"POLARIMETRIC STUDY OF THE PLANET MARS"

S U M M A R Y

In this paper we analyse five thousand two hundred measures of the polarized light of Mars, collected during the last nine apparitions of this planet, since 1948.

The polarization curves for the bright and the dark areas of the planet are reproduced for each one of the apparitions, for the wavelength of 0.61 micron.

The variation of the polarization for the spectral range 1.05 to 0.45 micron is examined.

The polarimetric and photometric study of selected samples of minerals enabled us to conclude the presence, in the bright areas of the planet, of a fine powder of hydrated iron oxide of the limonite type, the finer grains of this material wrap the larger ones; limonite could be a superficial coating on grains of absorbing material, resulting from atmospheric weathering.

The seasonal variation of the polarizing properties of the dark areas of Mars follows closely the variation of their darkness at Martian spring; this suggests a seasonal modification of their microscopic contexture.

The luminance of the atmosphere of the planet, free from veils or discernible aerosols of sizes larger than a fraction of wave-length, amounts, for  $\lambda = 0.61$  micron, to  $K_a(0.61 \text{ micron}) = 6.0 \times 10^{-4}$  stilb/phot; this corresponds to a surface pressure of 30 millibars.

Particles much smaller than the wave-length escape detection by the polarimetric techniques. Such particles, if any, increase the scattering power of the atmosphere. The above given atmospheric pressure should be considered in such a case as an upper limit.

The scattering coefficient of the atmosphere at 0.47 micron is  $K_a(0.47 \text{ micron}) = 15.10^{-4}$  stilb/phot. This value shows that the atmosphere of the planet is much too transparent in the blue to mask the markings of the soil. Nevertheless, due to the very low contrast between bright and dark areas in the blue, even very tenuous veils can make the surface markings disappear.

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INTRODUCTION :

In the present paper are grouped the measures of the polarized light of Mars collected since 1948. Since 1961, such measures have been particularly developed and extended to the Infra-red spectral region, thanks to a research contract with the U.S. Air Force (1).

In this paper are reproduced the polarization curves obtained during each one of the nine successive apparitions of the planet Mars in the course of the last 18 years.

Conclusions on the nature of the soil and the atmosphere of Mars have already been deduced from these measures (3)(4)(5). New results recently obtained and not published, are given in the present memo.

.....



## POLARIMETERS :

Two types of polarimeters have been used for the study of the planet Mars since 1948. The visual, fringe polarimeter is a model conceived by LYOT and the Infra-red photoelectric polarimeter worked out in the scheme of the present Research Contract with the U.S.A.F. (1).

1) Visual fringe polarimeter of LYOT : A description of this instrument has been given by LYOT in 1929 (2). Information on the same is equally given in a publication by A. DOLLEFUS, in 1955 (3). The visual fringe polarimeter of LYOT has been reproduced many times by the French Society Ets. Jobin & Yvon on behalf of a number of observatories. The instrument comprises a Savart polariscope placed between the eyepiece and the eye of the observer. This polarimeter gives a set of very close interference fringes when the incident light is polarized; the observer sees the planet striated by the fringes of the polariscope. A very thin celluloid plate is interposed in the beam; this plate can be tilted by the observer at will and introduces a polarization of the light allowing compensation of the polarized light of the planet, the compensation is accomplished when fringes disappear on the planetary region having the same polarization as the compensating plate. Moreover, an auxiliary plate, the principle of which is given in LYOT's article (2)(4), increases the sensitivity of the instrument and allows the observer to perceive visually, on small areas of the surface of the planet, proportions of polarized light of the order of 1 thousandth. A specimen of observation through this polarimeter is given later (see Fig. 1).

### 2) Photoelectric polarimeter :

The principle of this polarimeter was described in a note published in the "Comptes Rendus de l'Académie des Sciences" in 1958 by A. DOLLEFUS (6). A new modulator of polarized light was described in 1965 (7).

The polarimeter works according to the following procedure :

The light coming from the planet and collected by the telescope is focused by a Fabry lens giving a small image of the mirror of the telescope. In front of this lens, a compensator of polarization is introduced acting by reflection and transmission of light through a tilted plate according to Fresnel laws. The focal plane of the image of the mirror given by the lens coincides with the rotating wheel of the modulator of polarization. The purpose of the modulator is to introduce periodically fast rotations of  $90^\circ$  in the direction of polarization of the light.

The modulator (7) is followed by a birefringent prism, splitting the light into two beams and acting like two analysers working simultaneously at  $90^\circ$ . The non-polarized part of the incident beam is not altered by the modulator but only split into similar beams of constant intensity by the birefringent.

The polarized part of the incident light is alternately transmitted in each beam. The result is a flickering due to relative intensity of the two beams, proportional to the intensity of the polarized part of the incident light. The photoelectric cells are photomultipliers having caesium photocathodes on oxidized silver for the Infra-red measures, or antimony-caesium for measures in the visible or ultra-violet spectrum. For the far Infra-red we use lead-sulfide photocells.

The a.c. resulting current feeds a specially designed amplifier, the modulating frequency lying near 35 cycles/sec. The amplified current feeds a rectifier, synchronously attached to the optical modulation by the modulating wheel.

The gain of the amplifier is such as to give the level of fluctuations due to the photocell directly recorded by a microammeter. Operating the polarization compensator in front of the instrument, the observer is able to match exactly the unknown polarization, until the deflection of the microammeter is exactly cancelled, so long as fluctuations are observed. The sensitivity can be increased in proportion to the square root of the integration time by the use of an electric-flux integrator.

For the study of the planet Mars, we used a photoelectric polarimeter of the above type equipped with Infra-red cells for observation between 0,7 and 1,1 micron wavelength. A description of this instrument is given in the "Annual Summary Report No 2" of the Contract AF-61(052)-508.

Photocells are photomultipliers with 7 stages of dynodes increasing the photo current 1000 times. The photocathodes are caesium-coated silver with oxidation to increase the quantum efficiency in the Infra-red. The two photocells have to be cooled with dry ice.

This polarimeter is used with three selective filters isolating three spectral domains centered on the wavelengths, 0,83, 0,95 and 1,05 microns. The transmission curves of these filters are reproduced in the "Annual Summary Report No 3" of Contract AF-61(052)-508 and publication (8). At room temperature the instrument is able to detect at 1,05 micron a flux of polarized light of 2 to  $3 \cdot 10^{-9}$  Watts, with 1 sec. integration time.

When the photocells are cooled with dry ice, the threshold of sensitivity is reduced to about  $10^{-10}$  Watts. With the help of the integrating fluxmeter, successive integrations of several tenths of a second enable us to detect amounts of polarized light of the order of  $10^{-11}$  Watts.

Through a 40 inch telescope, the planet Venus gives a flux of the order of  $10^{-7}$  Watts, in which the polarimeter is able to detect an amount of polarized light of  $1/1000$ . On Mars, the flux is of the order of 10 times smaller, and requires integration to reach the same accuracy. On Jupiter, the flux of 2 to  $3 \cdot 10^{-8}$  requires successive sequences of integrations to give satisfactory results. The case of the Moon is simple, so that small areas of the surface can be selected, corresponding to soil materials of different albedos.

TELESCOPES :

a) The visual fringe polarimeters have been used since 1948, principally with refractors, in view of the fact that refractors give sharper images than reflectors for the measurement of small areas localized on the surface of the planet Mars. The visual polarimeters were used in France with the following instruments :

1) The 60 cm. refractor of the Pic-du-Midi Observatory, in the Pyrenees (alt. 2870 m.). This refractor was mounted at this Observatory by B. LYOT in 1943, specially for the study of the surfaces of planets with a high resolving power. A description of this instrument has been given by LYOT in 1955 (9). The particular application of this refractor in polarimetric measurements was described in 1955 by A. DOLLEFUS (3).

2) The 83 cm. refractor of the Meudon Observatory. This instrument, which is the largest refractor so far built in Europe, was recently modernized by P. MULLER and has operated since 1965 in the field of polarimetry. A description of this instrument has been given by P. MULLER in 1965 (10).

3) The 30 cm. refractor of the Meudon Observatory. In order to discharge the instruments of great aperture, when no high resolution is required, a small 30 cm. aperture refractor was mounted in 1964 at the Meudon Observatory. The object glass ratio is  $f/10$ . The instrument with its equatorial mounting is housed in a mobile cabin in the Observatory's park. Through this instrument, a great number of polarimetric measures of the whole planet Mars or the large bright and dark areas of its surface were secured.

Furthermore, the visual fringe polarimeter was used from time to time with the 43 inch reflector of the Pic-du-Midi Observatory, principally for taking measures in blue light.

b) The photoelectric polarimeters measure the light coming from the whole planet in the Infra-red domains. It requires a large quantity of light. Consequently, such polarimeters are used with reflectors of great aperture. Our Infra-red polarimeter was used with the following two instruments :

1) The 40 inch reflector of the Meudon Observatory. This old instrument was put into operation these last years, thanks to the U.S.A.F. Research Contract AF-61(052)- 508 (1). The ancient Newtonian arrangement has been transformed into a Cassegrain-coudé combination. A complete description of the relative optical and mechanical modification is given in the "Annual Summary Report N° 2" of the said Contract. In the same Report are also given the tests of the qualities of the optical surfaces as well as the measurement of the parasitic polarization introduced by the coudé mirror. The way of carrying out measurements for the correction of the instrumental polarization is described in the "Annual Summary Report N° 3" and a publication of 1965 (8).

2) The 43 inch reflector of the Pic-du-Midi Observatory : This new

instrument, put into operation these last years at the Pic-du-Midi Station, was used whenever it was necessary to take measures on planets of lower albedo, such as Jupiter or Mars when at a great distance from the Earth. A description of this instrument was published by J. Rösch (11).

# STUDY OF THE POLARIZATION OF THE LIGHT OF MARS :

The purpose of the measurements of the polarization is the determination of the quantity

$$P = \frac{I_1 - I_2}{I_1 + I_2}$$

which is called "proportion of polarized light".  $I_1$  and  $I_2$  are the intensities of the two components of the transverse orthogonal vibrations. This quantity "P" varies from one point of the disc of the planet to another, as a function of the phase angle "V" at which the planet is observed. Plotting on a graph the proportion of polarized light P as a function of the phase angle, we obtain the curve of polarization for a given area of the disc of Mars.

The photoelectric measures collected these last years referred to the light of the whole disc and gave the global curve of polarization of the planet.

The measures taken through the visual polarimeter referred to small areas localized on the disc. A. DOLLFUS has undertaken measures of different areas of Mars since 1948 (3)(4)(5). J.H. Focas joined this great program from 1954 (12)(13). The observations were also able to be developed thanks to co-operation between observatories spread over different longitudes throughout the world which joined the said program. The observatories of Pic-du-Midi Meudon, Athens, Harvard and Kiev contributed to this observational campaign, coordinated by the International Astronomical Union through its Commission 16 "Physical Study of Planets and Satellites". Since 1961, the U.S.A.F. Research Contract .F-61 (052) - 508 has allowed a larger development of these observations. We now have at our disposal more than 5200 measures taken during the 9 last apparitions of the planet Mars since 1948. Table № I gives the measures taken in orange light during each one of the apparitions and contains : the Observatory, the Observer, the number of observing nights, the number of measures and their total number for each opposition. All measures reported in this Table were taken with the visual fringe polarimeter of LYOT and refer to small areas of the Martian surface with the exception of those taken at Kiev Observatory by Morozenko through a photoelectric photometer.

Fig. I gives an example of an observing session through the visual polarimeter : the values of the proportion of polarized light P are expressed in thousandths; they refer to areas of the surface of the planet of a size of 1.5 sec. of arc. The measures are accompanied by appreciation on the transparency of the Martian atmosphere; a drawing taken in blue light is added for information. Moreover, the longitude of the central meridian  $\lambda$ , the latitude of the center of the disc  $\varphi$ , the apparent diameter of the disc d, the phase angle V and the heliocentric longitude  $\ell$  of the planet, are given.

The observation reproduced in Fig. I was taken on February 26, 1965 for the phase angle  $V = 15.5$ ; the proportion of polarized light on the bright areas at the center of disc was -4.2 thousandths; this value persists on the rising limb on the right, which was considered to be free from any appreciable

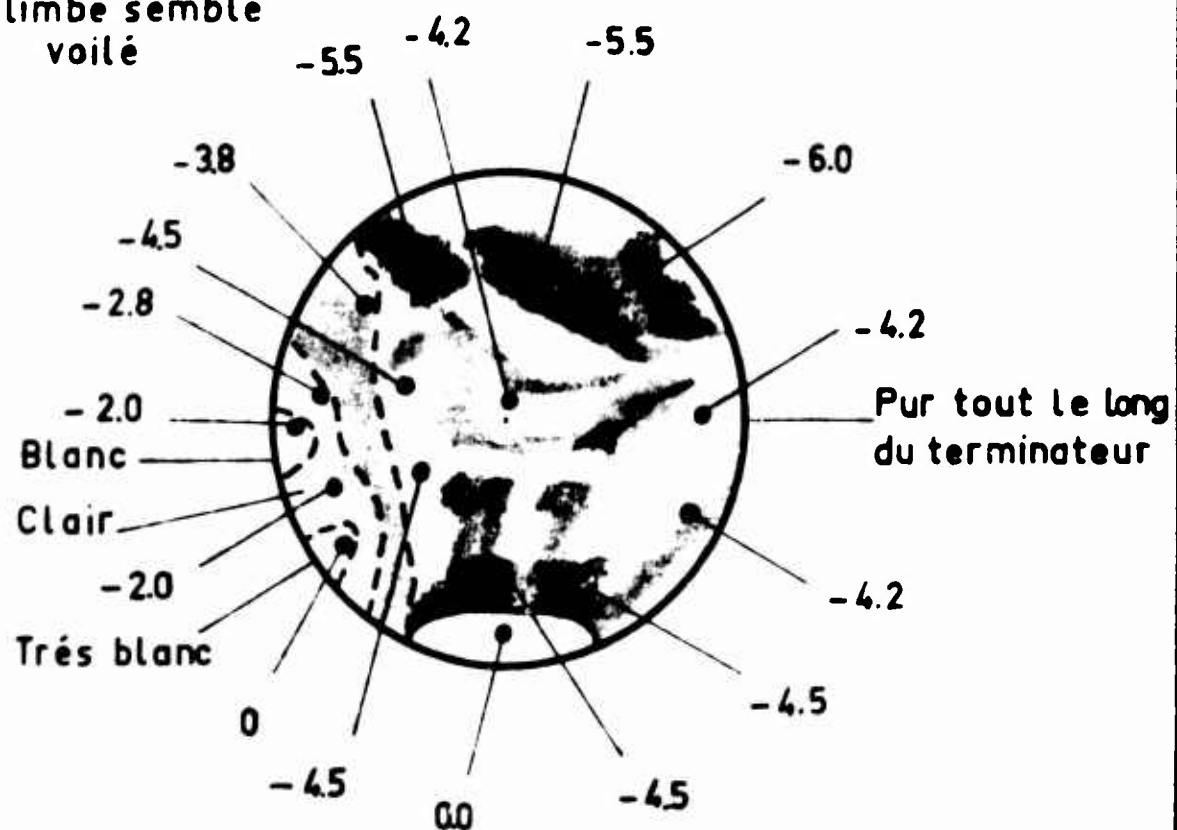
26 FEVRIER 1963 18H35 à 19H00 T.U.

$$\omega = 185^{\circ} \quad V = 15^{\circ}5$$

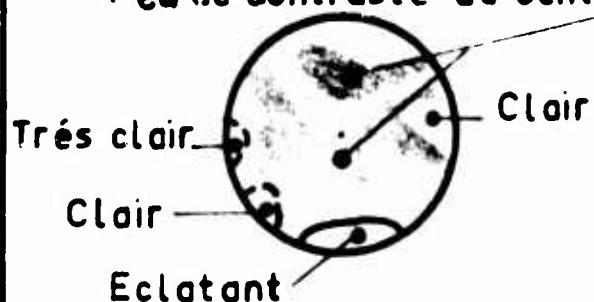
$$\varphi = +12^{\circ}6 \quad \eta = 144^{\circ}6$$

$$d = 12''8$$

Le limbe semble  
voilé



Peu de contraste au centre



OBSERVATOIRE PIC DU MIDI  
REFRACTEUR DE 60cm  
POLARIMETRE DE LYOT  
AUDOUIN DOLLFUS

19H45 Filtre bleu W.47.B

ASPECT DES VOILES EN BLEU



atmospheric veil. The dark areas show a stronger negative polarization. The polar cap shows a zero polarization. At the setting limb, on the left, strong anomalies of the polarization characterize veils made manifest by their white appearance along the limb of the planet; such veils disturb the polarization to a greater extent than that seen by the visual observer.

One of the two white spots, at the limb, shows a zero polarization of the clouds but characterizes a hoar frost deposit analogous to that of the polar caps. Similar observations taken previously have already shown that this area called "Nix Olympica" should be a high mountain mass wrapped in a cloudy veil with some peaks covered by hoar frost which seem to emerge from the cloud layer.

Observations of this kind, collected in 1948, 1950 and 1952 have already been published, as well as the analysis of the relative results, by A. DOLLEFUS in 1955 (3). Some observations taken during the apparitions of 1961, 1963 and 1965 have not been published and are reported in the present memo.

Since 1963, thanks to the support of a Research Contract with the U.S. Air Force, observations have been carried out with the visual fringe polarimeter in different spectral regions, covering the spectrum from the visible red to the blue and have been extended in the Infra-red to 1,05 micron by means of the photoelectric polarimeter (14).

TABLE I

MEASURES OF THE POLARIZED LIGHT OF MARS IN ORANGE LIGHT - 0.61 MICRON

Year	Observatory	Observer	Observing nights	Number of measures	Total
1948	PIC-DU-MIDI	DOLLEFUS	25	350	350
1950	PIC-DU-MIDI	DOLLEFUS	33	300	300
1952	PIC-DU-MIDI	DOLLEFUS	31	330	330
1954	PIC-DU-MIDI	FOCAS	41	440 )	756
		DOLLEFUS	5	55 )	
	ATHENS	FOCAS	32	260 )	
1956	PIC-DU-MIDI	DOLLEFUS	46	477	1308
		FOCAS	37	580	
	ATHENS	FOCAS	20	251	
1958	PIC-DU-MIDI	FOCAS	21	372 )	628
	ATHENS	FOCAS	26	256 )	
1960-61	PIC-DU-MIDI	FOCAS	34	345 )	435
		MORIN	6	30 )	
	ATHENS	FOCAS	7	62 )	
1963	PIC-DU-MIDI	DOLLEFUS	14	170 )	517
		MAURICE	6	50 )	
		MORIN	4	19 )	
	ATHENS	FOCAS		214 )	
	KIEV	MOROZENKO	33	61 )	
	HARVARD	A. YOUNG	3	3 )	
1965	PIC-DU-MIDI	DOLLEFUS	29	330 )	666
		FOCAS	9	64 )	
	MEUDON	FOCAS	60	185 )	
		DOLLEFUS	10	61 )	
	KIEV	MOROZENKO	26	26 )	



### POLARIMETRIC STUDY OF THE PLANET MARS IN 1963

In 1963, we requested that, in the scheme of the activities of the Commission I6 of the International Astronomical Union "Physical Study of the Planets and Satellites", different observatories situated at different terrestrial longitudes and equipped with polarimeters, carry out polarimetric observations with a view to a concerted study of the planet Mars. Thanks to the support of Intern. Astr. Union, the Observatories of Pic-du-Midi, Meudon, Athens, Kiev and Harvard carried out such observations which have been analysed at the Meudon Observatory, Fig. 2 gives a specimen of the measures taken on the bright areas of Mars at the center of the disc. The observatories are characterized by different symbols. The proportion of polarized light is expressed in thousandths. The measures taken by the different stations agree to one thousandth approx. and do not seem to depend upon the Observatory, Observer, or instrument. The curve, in heavy line, gives the polarization of the soil of Mars, its atmosphere being free from apparent veils. The discrepancies characterize the status of purity of the Martian atmosphere; in fact there are white veils of ice crystals and yellow veils of fine dust, persisting sometimes in the planet's atmosphere and perturbing the polarization. Their polarizing properties have been studied in previous publications (3) (4)(5)(12)(13). On Fig. 2, the measures taken between a and b cover the period 1st to 30th December 1962; they are in agreement with the mean curve of the bright areas traced with heavy line, established in the absence of veils; it results that during the period concerned the Martian atmosphere was very pure. From the 1st to the 15th of January 1963, i.e., between b and c on the figure, light haze, often invisible, affected the transparency of the Martian atmosphere; from c to d, the angle of vision was too small to obtain significant results. Between 15th February and 30th March 1963, from d to e, exceedingly scattered measures and very low values indicate the presence of yellow veils complementing some ice crystal clouds. Till the middle of May, from e to f, the yellow veils disappeared, but some localized haze of ice crystals, manifested by anomalies at the disc's limb, induced a further scattering of the measures.

The detailed study of observations similar to those of Fig. 1 allow the localization and density of the atmospheric veils or the dust clouds and establish the manner of their evolution. Such a study does not enter into the scheme of the present publication. The observations are grouped at the Meudon Observatory where they are available for the study of the Martian clouds as required.

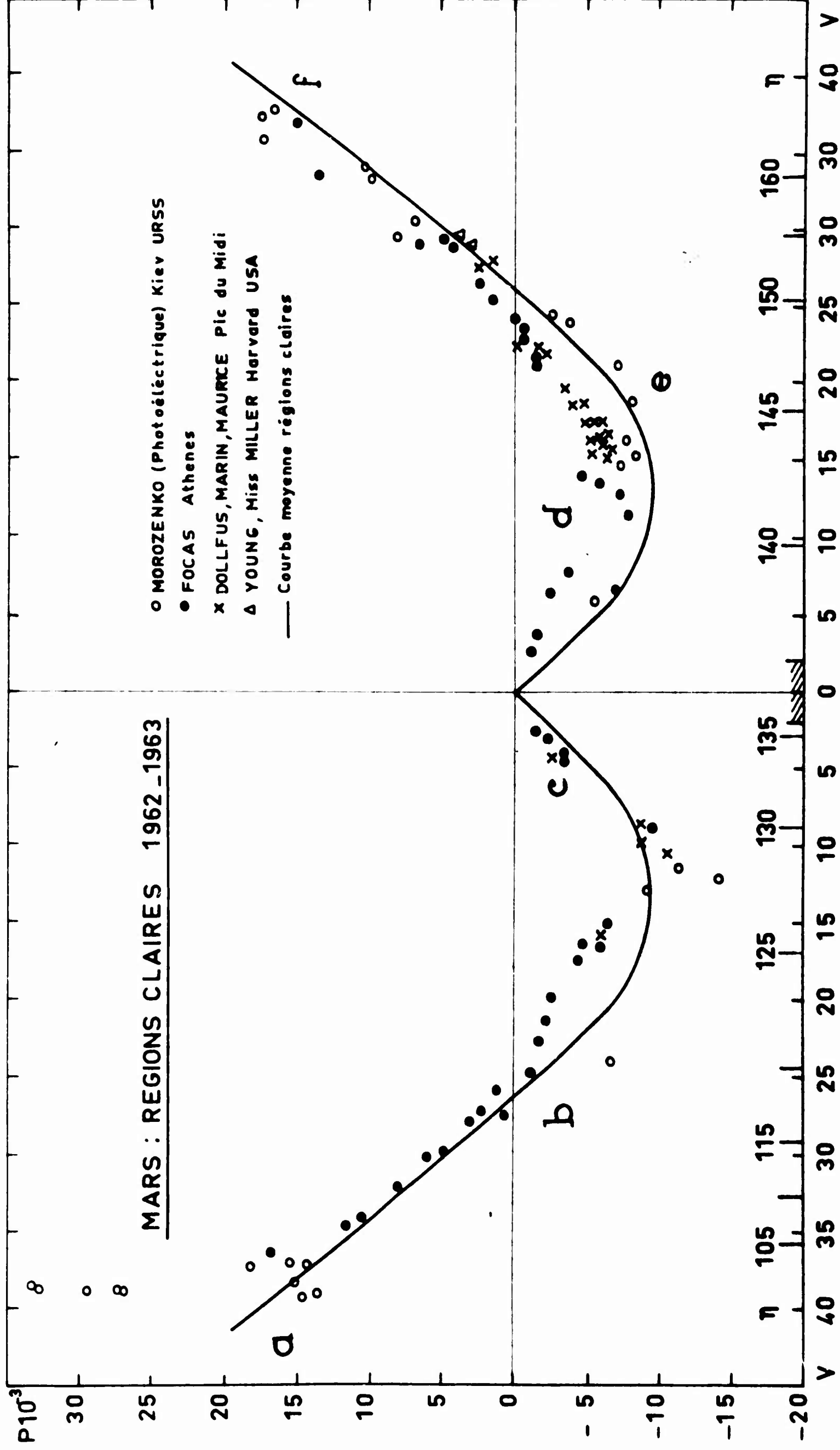


Fig. 2

POLARIMETRIC STUDY OF THE PLANET MARS IN 1965 :

During the apparition of 1965, corrected observations were undertaken at Pic-du-Midi and Meudon Observatories by A. DOLLFUS and J.H. FOCAS, the different telescopes of the two Observatories were used simultaneously. The measures have been obtained with the visual polarimeter through 5 colour filters cutting down the spectral domain by intervals centered respectively on 0.47, 0.50, 0.53, 0.60, 0.63 micron. The photoelectric polarimeter was used in the domains : 0.83, 0.95, and 1.05 micron. All measures are reported in Table II. Figure 3 shows the measures obtained on the bright areas of Mars at the disc's center for a wave length of 0.60 micron.

TABLE II

MEASURES OF THE POLARIZED LIGHT OF MARS IN DIFFERENT WAVE LENGTHS

Observatory	Instrument	Number of Measures - 1965									
		Visual fringe polarimeter of Lyot					Photoelectric Polarimeter				
		$\lambda=0.47$	$\lambda=0.50$	$\lambda=0.53$	$\lambda=0.60$	$\lambda=0.63$	$\lambda=0.83$	$\lambda=0.95$	$\lambda=1.05$		
MEUDON	30cm Refractor	24	26	44	26						
	83cm Refractor	6	24	84	12						
PIC-DU-MIDI	60cm Refractor	7	3	3	60	2					
	107cm Reflector	7	51	50	187	31	22	21	2		

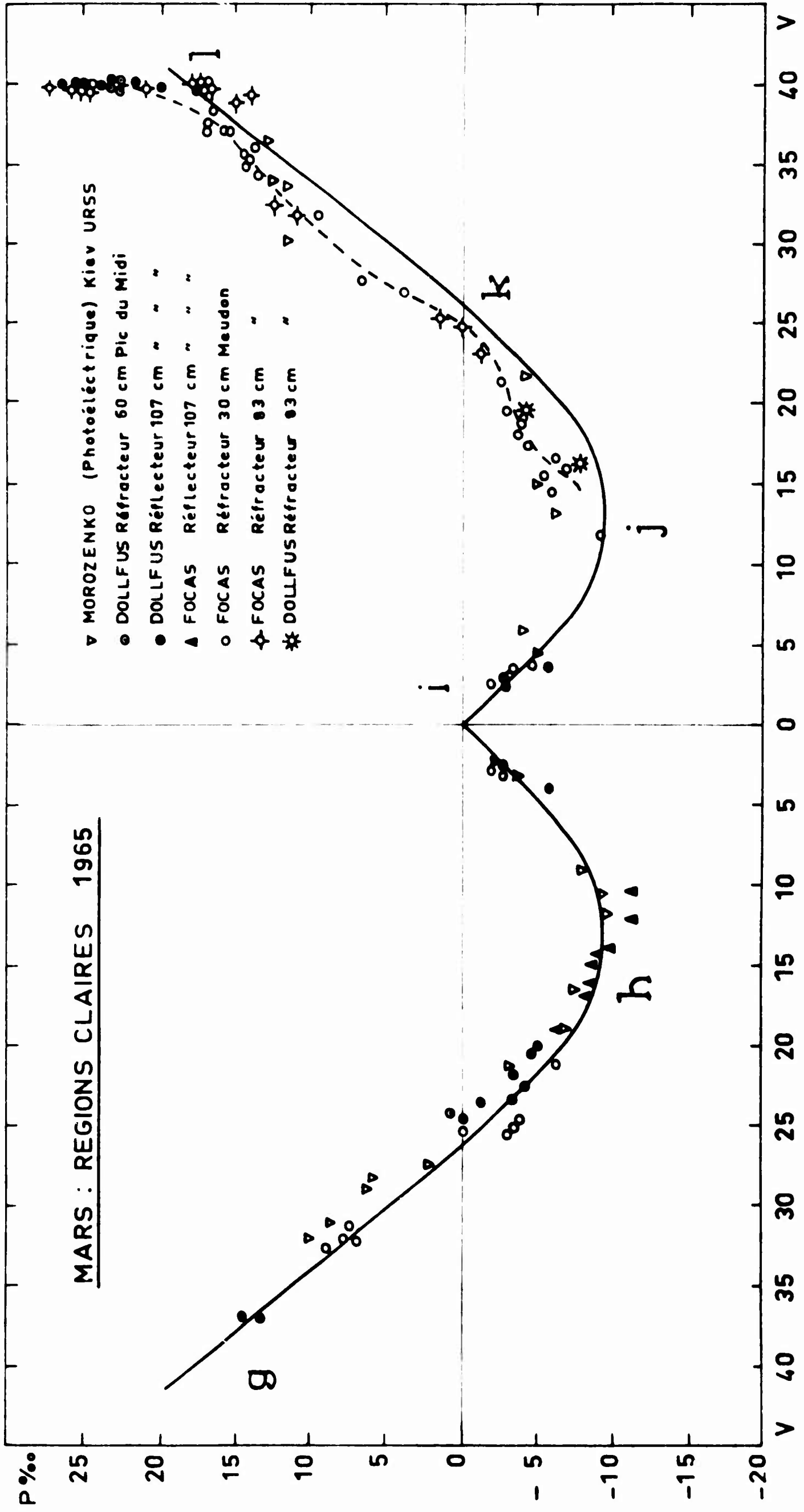


Fig. 2

The curve traced with a heavy line shows the polarization of the soil when the Martian atmosphere is particularly transparent. From December 1964 till the end of 1965, from g to h on the curve of fig.3, the polarization characterizes the soil of the planet seen through a very pure atmosphere. During the last period, from j to l, there are discrepancies among the measures of polarization, due to the rather frequent presence of veils, which seem to consist of ice crystals. The measures taken on the dark areas of the surface of the planet are reported in fig. 27.

Fig. 4 and 5 show the polarization curves of the bright areas of Mars measured at the center of the disc through different colour filters. As it results from fig. 4, the shape of the polarization curves varies very slightly with the wave length in the Infra Red range. Fig. 5 shows a progressive diminution of the phase angle for which the polarization is zero and the increase of the slope of the positive part of the curve. It will be shown later that such properties characterize the atmosphere of the planet Mars and allow a determination of its transparency in blue light.

By the end of June 1965, the phase angle reached the value of  $V = 39^\circ$ , which was the maximum accessible value of that year. We reported on Fig. 6 and 7 the proportions of polarized light measured on the bright areas at the center of the disc as a function of time, during the months of May, June and July, for each one of the spectral domains, red, orange, green and blue-green. The heavy line shows what should be the variation of the polarization if the atmosphere of the planet were free from veils. It can be ascertained that this was the case during the month of May; on the contrary, in June, strong discrepancies of the polarization have been recorded for each one of the four wave lengths, all in the positive sense. Such discrepancies are explained by the presence of faint veils of ice crystals. These veils were observed as diffuse white formations; but for the most part, there was but a slight increase of the polarization of the light when these regions were seen obliquely along the rising or the setting limbs of the planet.

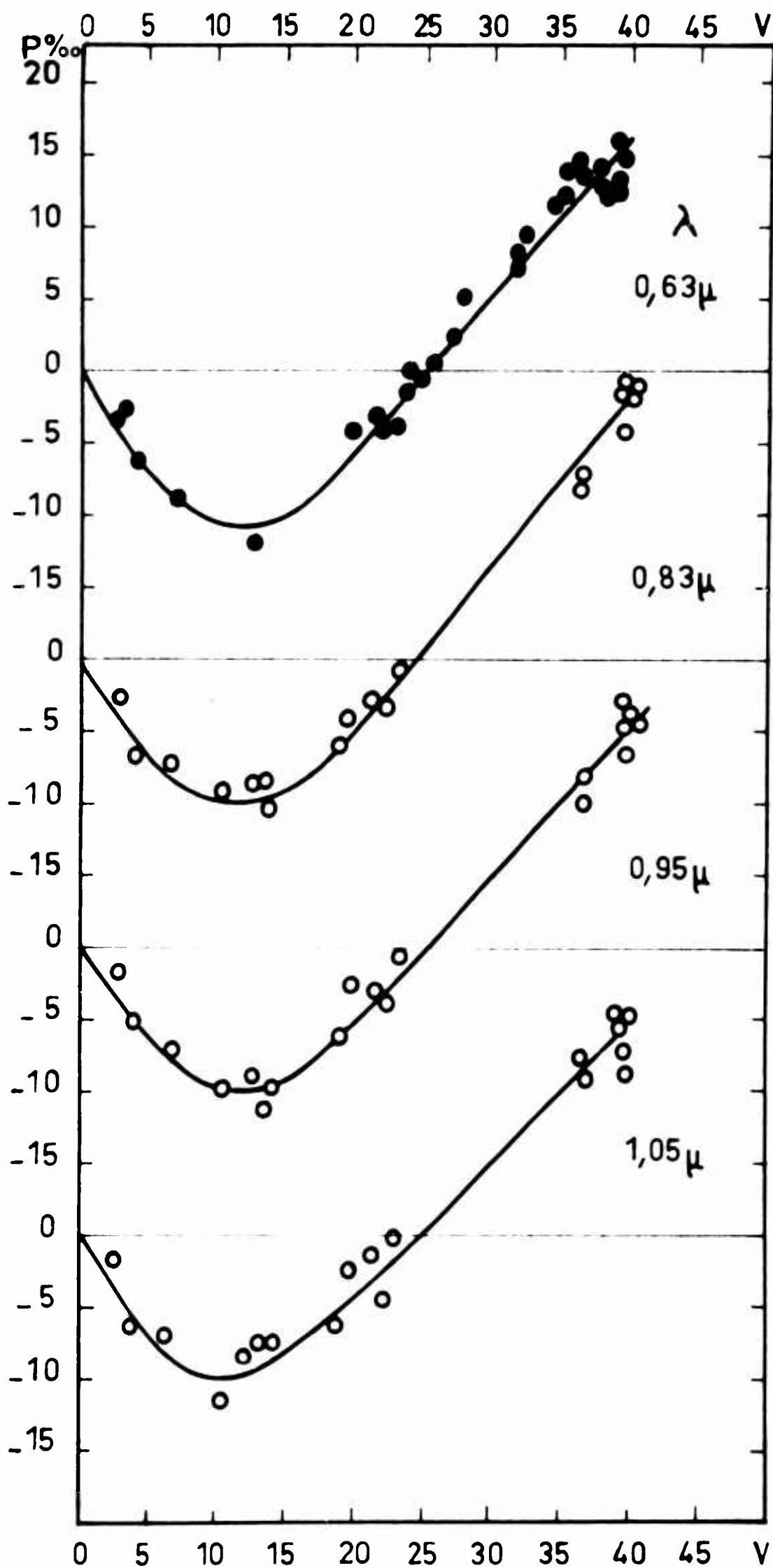
During this epoch the Martian atmosphere seemed to be free from dust clouds; the presence of such clouds, if any, should be revealed by a diminution of polarization. Fig. 6 and 7 show that the discrepancies of the polarization given by the white veils are stronger towards the red than towards the blue.

We shall see later how these observations allow the determination of the transparency of the atmosphere of Mars in blue light.

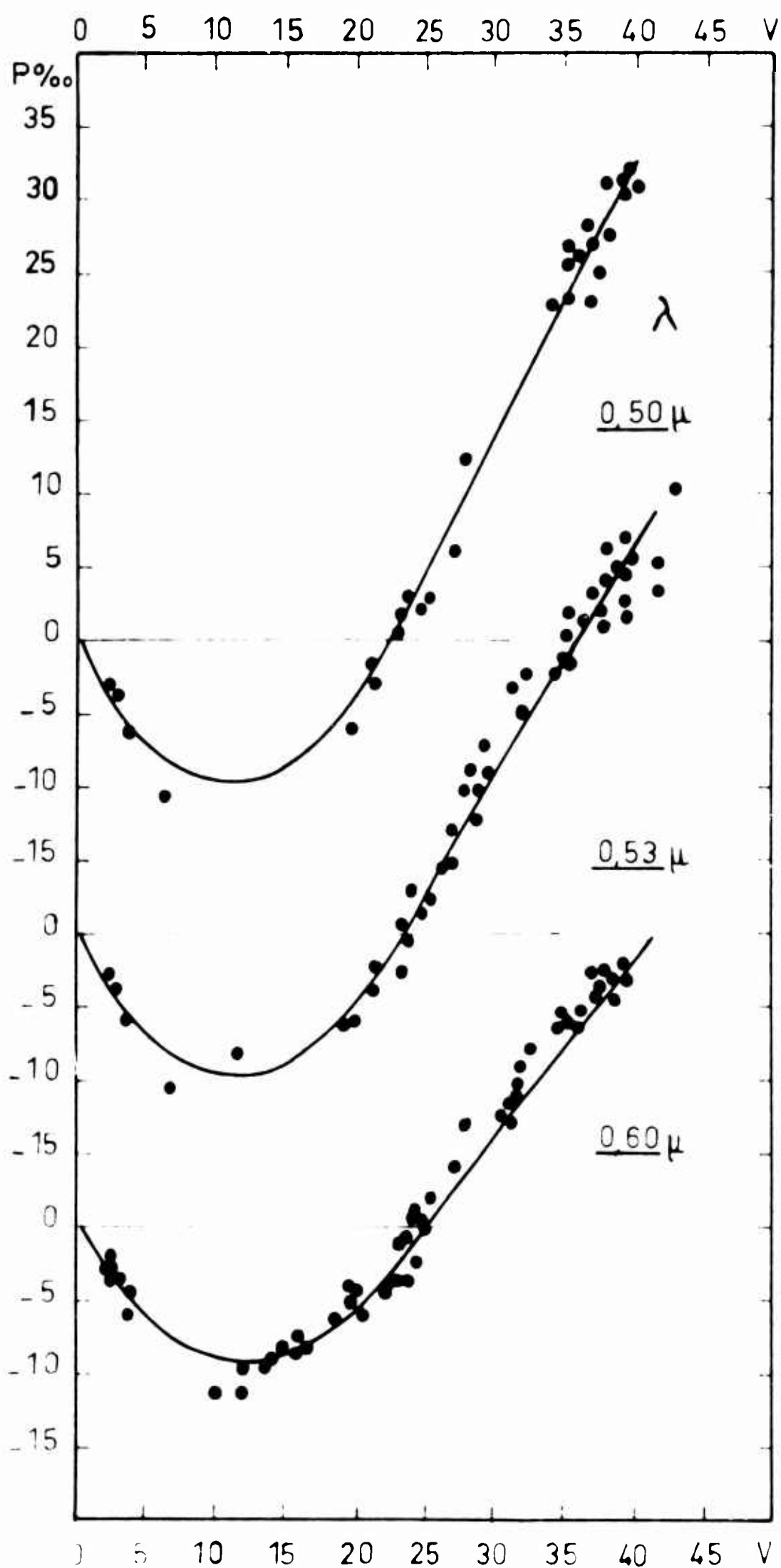
MARS 1965

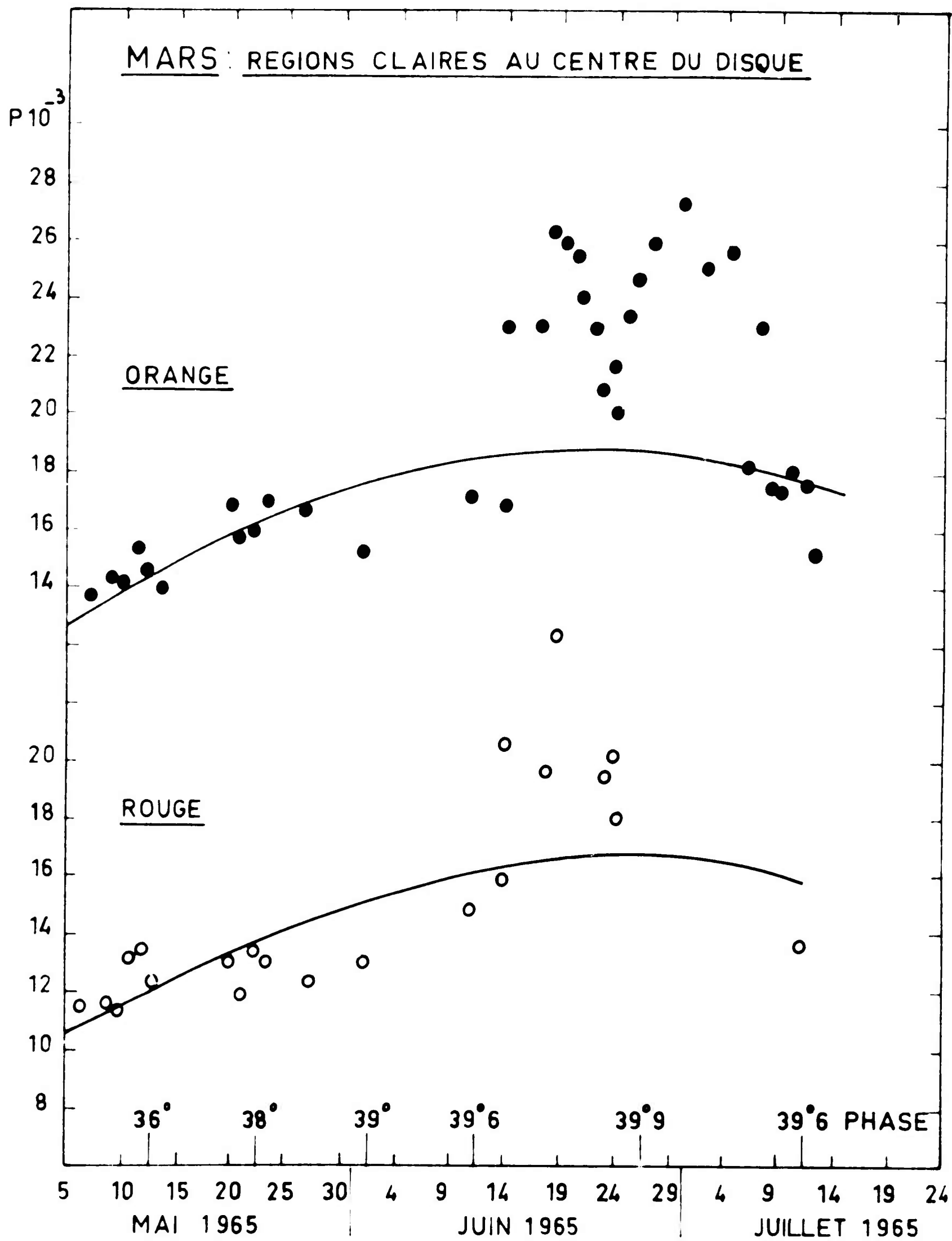
● VISUEL

○ PHOTOELECTRIQUE

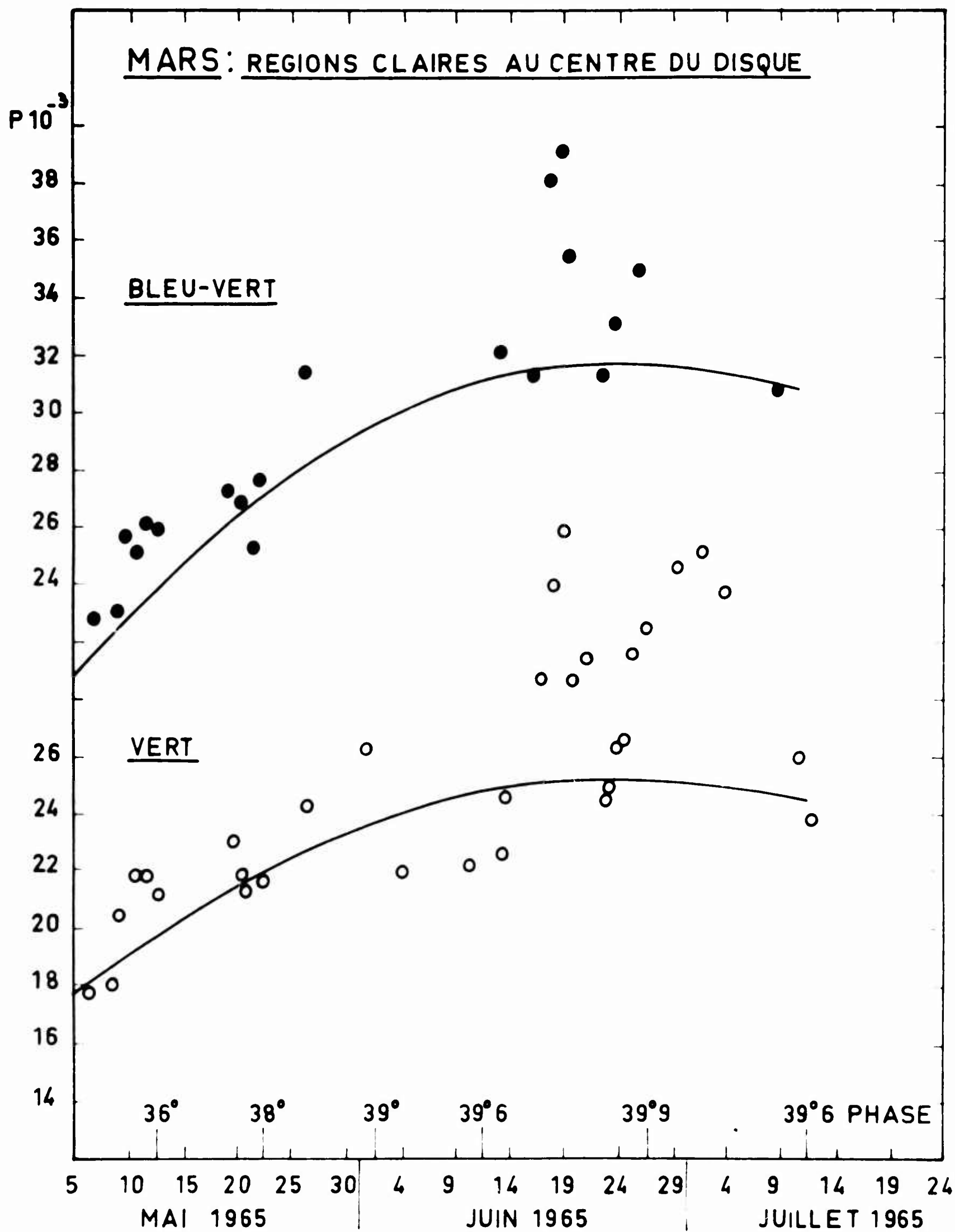


# MARS. REGIONS CLAIRES







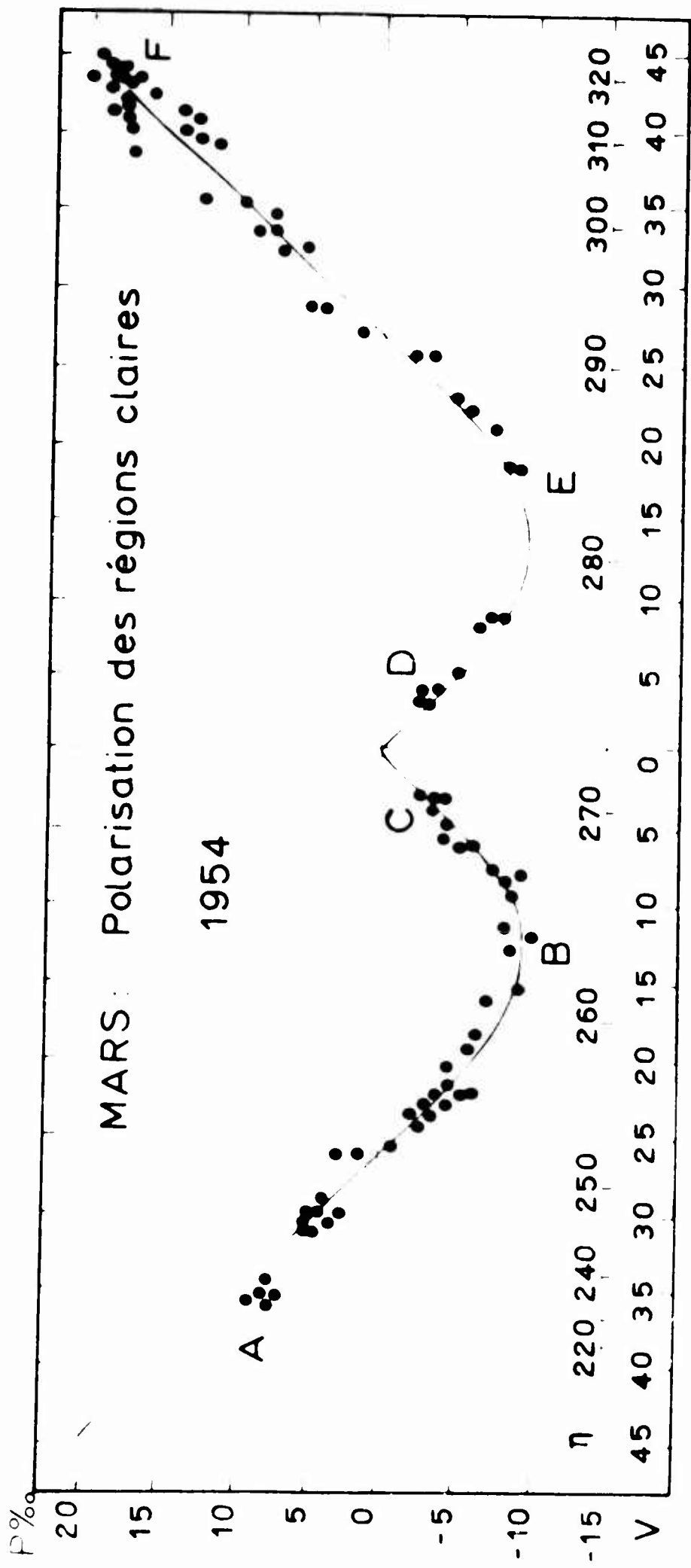


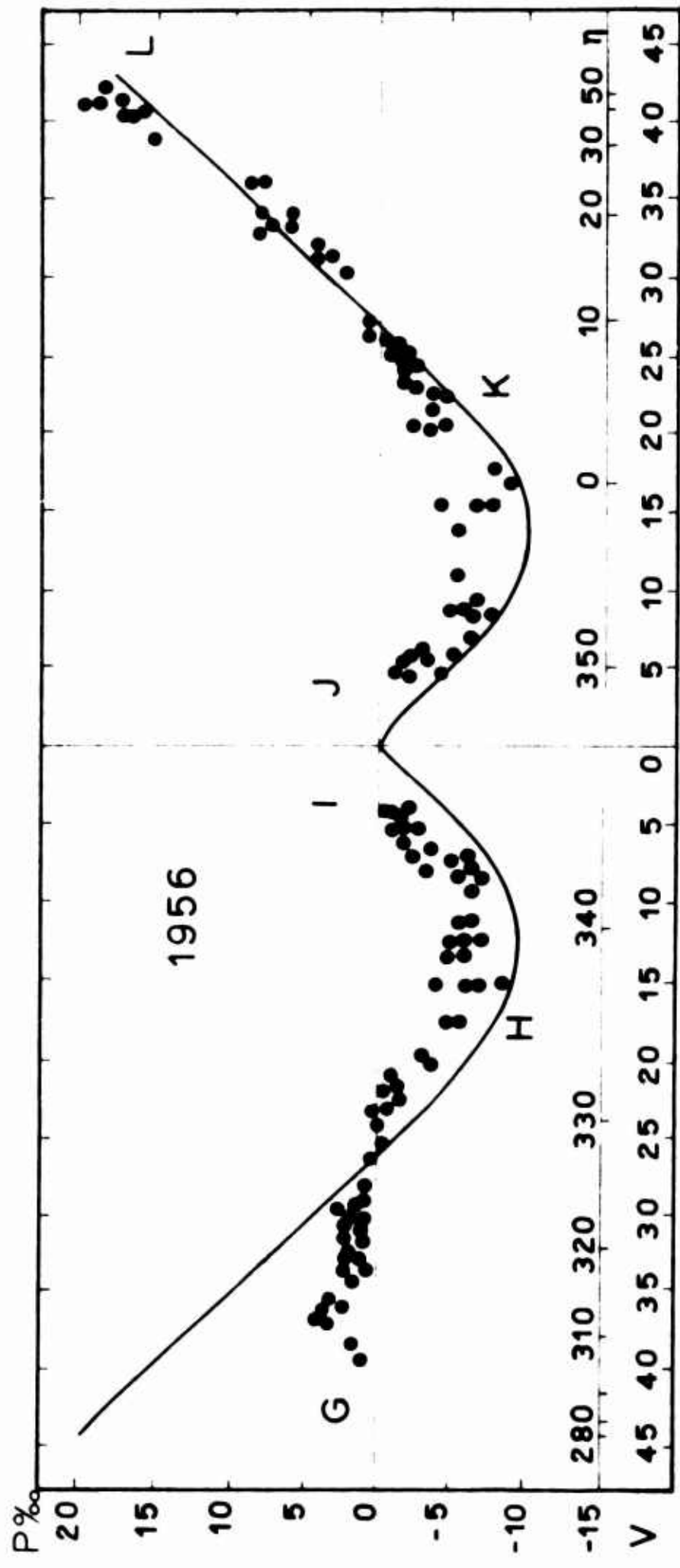
SURVEY OF THE POLARIMETRIC MEASUREMENTS OF THE LIGHT AREAS OF MARS :

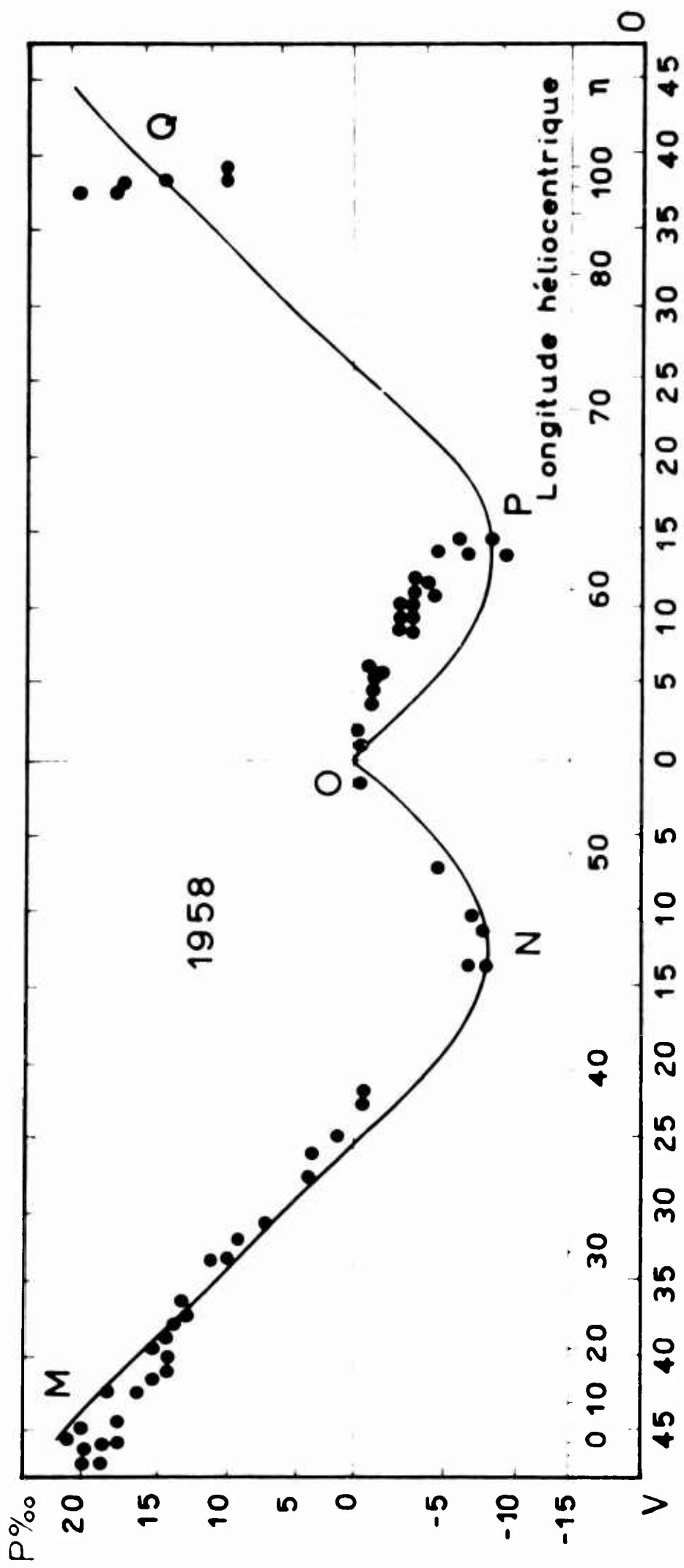
Since the beginning of our observations, took place successively, the following apparitions of Mars : 1948, 1950, 1952, 1954, 1956, 1958, 1960, 1963 and 1965. For each one of these apparitions, we traced polarization curves of the bright areas of the planet at the center of the disc. Curves concerning the apparitions of 1946, 1948, 1950 and 1952 have already been published in 1955 (3). The observations of 1954 to 1965 are reported on Fig 8 to 13. Each one of these figures gives in abscissae the phase angle and the heliocentric longitude of the planet and in ordinates the proportion of polarized light. Heavy lines represent the polarization of the soil of Mars when it is observed through the atmosphere of the planet free from veils or clouds. In 1954, Fig. 8, the atmosphere of the planet seemed to be particularly transparent during the whole apparition. On the contrary, in 1956, Fig. 9, it was particularly disturbed by persistent yellow veils, recorded by numerous observers. In 1958, Fig. 10, the Martian atmosphere was transparent during the first part of the observational period up to the opposition ; afterwards, the polarization revealed the presence of some yellow veils ; such veils would escaped any other observational procedure than polarization.

In 1960, the Martian atmosphere as a whole was sufficiently pure, fig. 11.

The observations of 1963 and 1965 (fig. 12 and 13) have been commented previously.







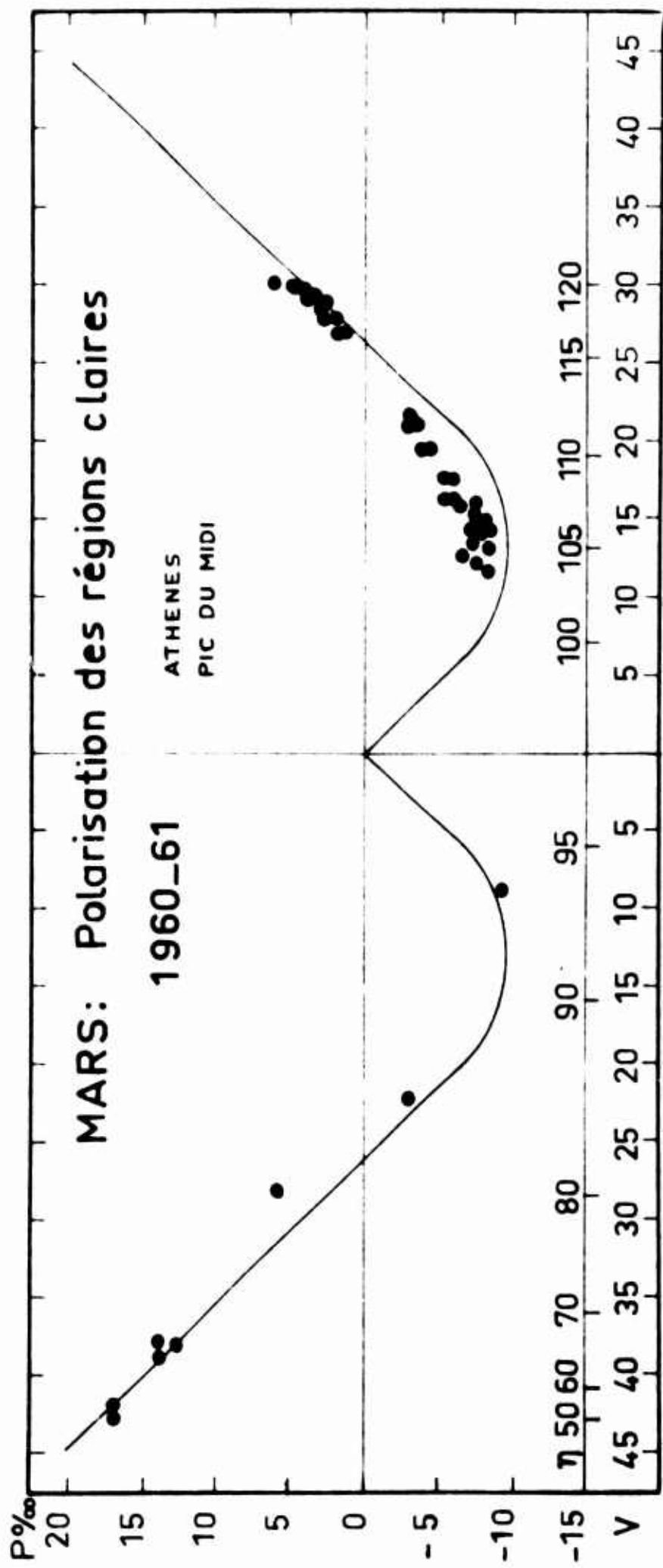


Fig. 11

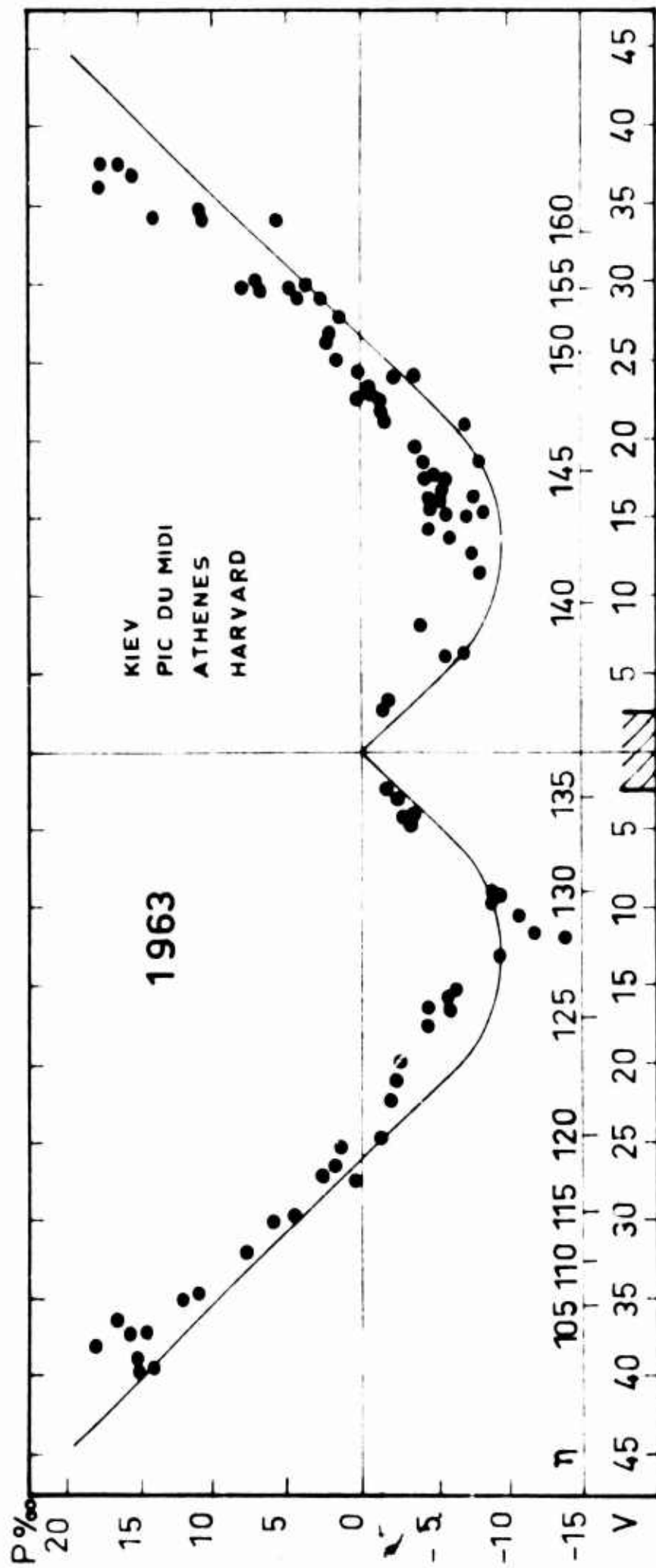


Fig 12

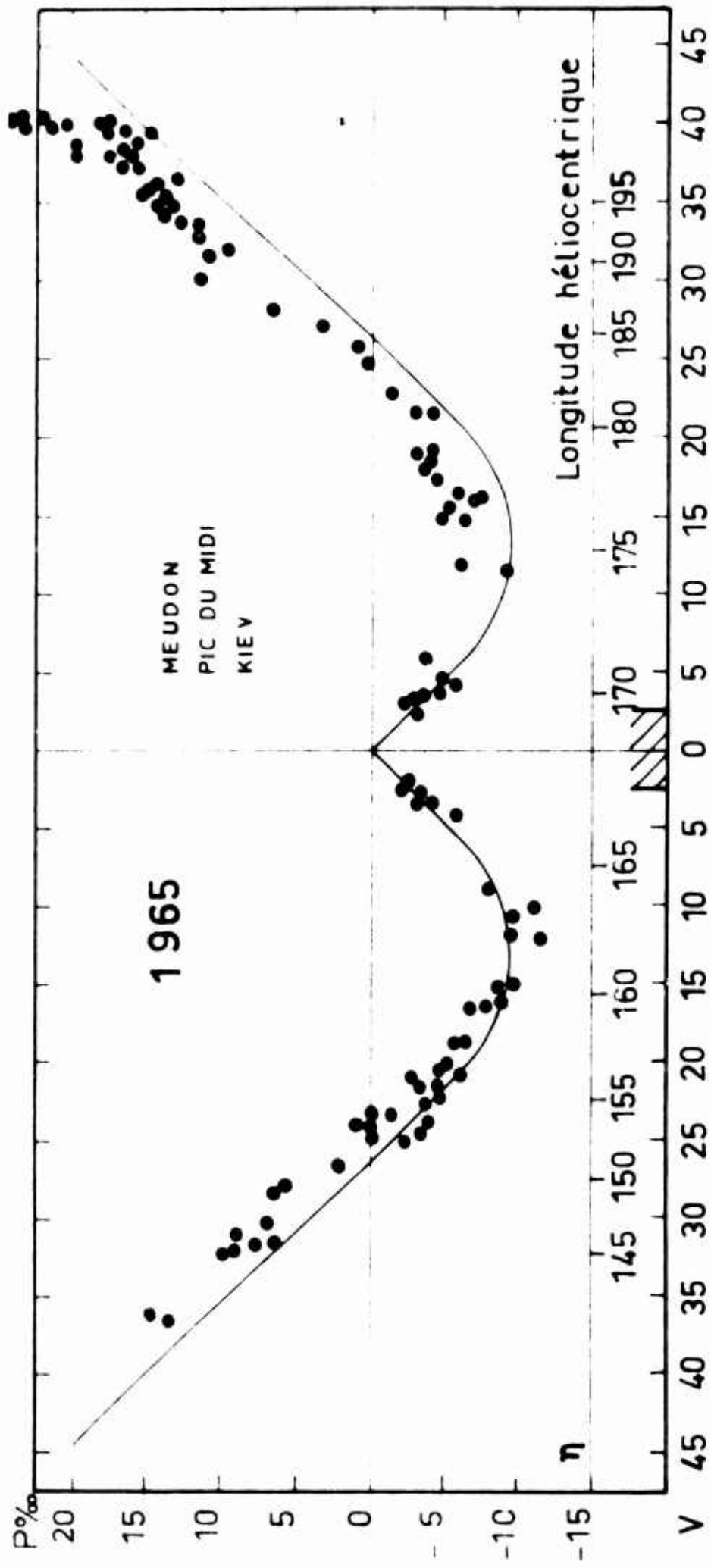


Fig 13



# IDENTIFICATION OF THE NATURE OF THE SOIL OF THE PLANET MARS :

The polarization of the light of the bright areas of the surface of Mars allows the interpretation of the nature of the soil of this planet.

a) Previous investigations : The first researches for the identification of the nature of the soil of Mars by means of the polarization of the light, have been published in 1951 by A. DOLLFUS (15). These studies can be summarized as follows (3) :

"Studies developed in the laboratory, show that such polarizations necessarily characterize a very absorbent, pulverized and opaque substance.

There are but very few substances which show an inversion of the polarization for such a high phase angle as  $28^\circ$ ; this material, moreover, shows a negative polarization when observed obliquely; such a negative polarization is not usually associated with the above stated property of inversion of the polarization at  $28^\circ$  angle of vision. It restricts the field of study to well defined substances and favours the selection of a sample.

Different red sandstones very absorbent, crushed, pulverized or sifted in various ways have been tried, but none shows such a pronounced negative polarization as the Martian soil, and none an inversion of the polarization for such a high angle as  $28^\circ$ .

Pulverized silicates and metallic oxides of a deep brown colour have been studied :

- Pyroxene : Augite  $\text{SiO}_2$  (Fe, Ca, Mg)O in brown-yellow powder.
- Amphibole : Hornblende  $\text{SiO}_2$  (Al, Fe, Ca, Mg)O in deep brown-yellow powder.
- Zirconium Oxide : Zircon  $\text{SiO}_2$ ,  $\text{ZrO}$  in very light yellow-orange powder.
- Titanium Oxide : Rutile  $\text{TiO}_2$  in deep brown-red powder.

None of these substances, as regards their polarimetric properties, shows any connection with those of the soil of Mars.

Measures taken on a number of samples of volcanic ashes of great variety, give, sometimes, polarimetric curves identical to those given by the bright areas of the soil of Mars; nevertheless, their colours differ, in general, from the specific yellow colour of the Martian areas.

The Iron Oxides in different forms, according to their state of hydration, can show such polarizations by oblique viewing and an inversion at phase angle  $28^\circ$ . Non-hydrated Hematite (oligist iron)  $\text{Fe}_2\text{O}_3$  in cherry-coloured powder, sifted in small grains, as well as its red-ochre variety, are far from reproducing the polarimetric properties of the Martian soil.

But hydrated samples of goethite  $\text{Fe}_2\text{O}_3 \cdot \text{H}_2\text{O}$  in yellow or yellow-ochre powders, particularly the yellow-brown Limonite,  $\text{Fe}_2\text{O}_3 \cdot 3\text{H}_2\text{O}$  of 0.20 albedo,

reproduce exactly the polarization of the bright areas of Mars".

Since that epoch, a great many confirmations or discussions on the identification of the limonite have been published, but they are mostly based on photometric studies or theoretical considerations. V.V. SHARONOV (16), through an extensive research of the photometric properties of the bright areas of Mars and those of samples of terrestrial substances, was able, in 1961, to identify the presence of limonite in the form of an ochre powder, in the bright areas of the planet.

A. BINDER and D. CRUIKSHANK (17)(18) studied the reflectivity of Mars in the Infra-red and concluded that iron oxides of limonite type could probably be the constituent of the bright areas of the planet, in which case weathering of the surfaces of grains causes a coating of limonite.

D. HOVIS (19), as well as C. SAGAN and his colleagues (20) measured in the laboratory Infra-red spectra of limonite and concluded its probable existence on Mars.

J.A. ADAMCIK and his colleagues (21) prepared artificial samples of silicates coated with limonite to reproduce the weathering effect.

R.L. YOUNKIN (22), nevertheless, obtained Infra-red spectra of Mars, which do not seem to conform to the identification of limonite.

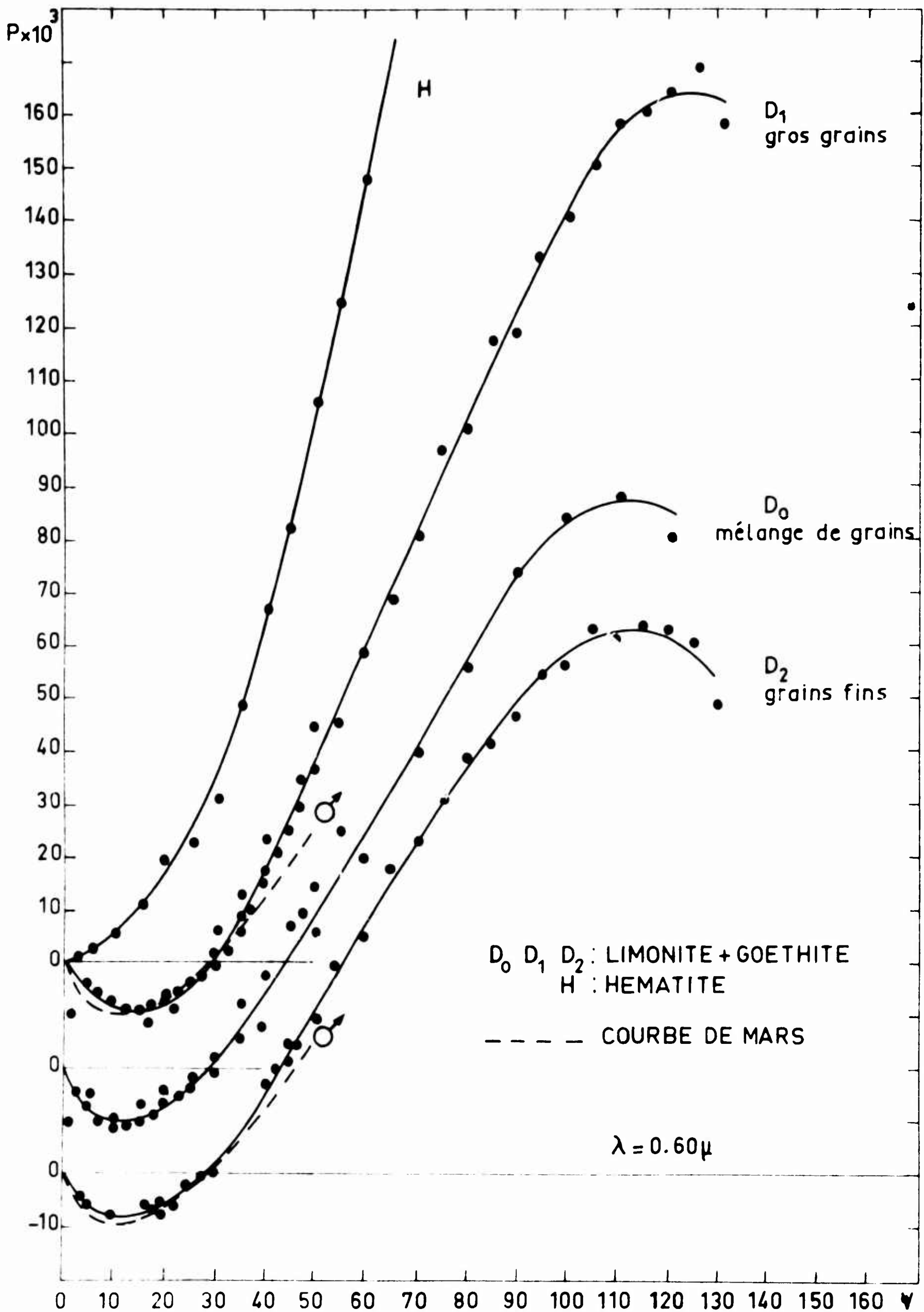
J.W. SALISBURY and his colleagues (23)(24)(25) as well as C. SAGAN (26) examined, from the geological point of view, the possibility of the existence of limonite on Mars.

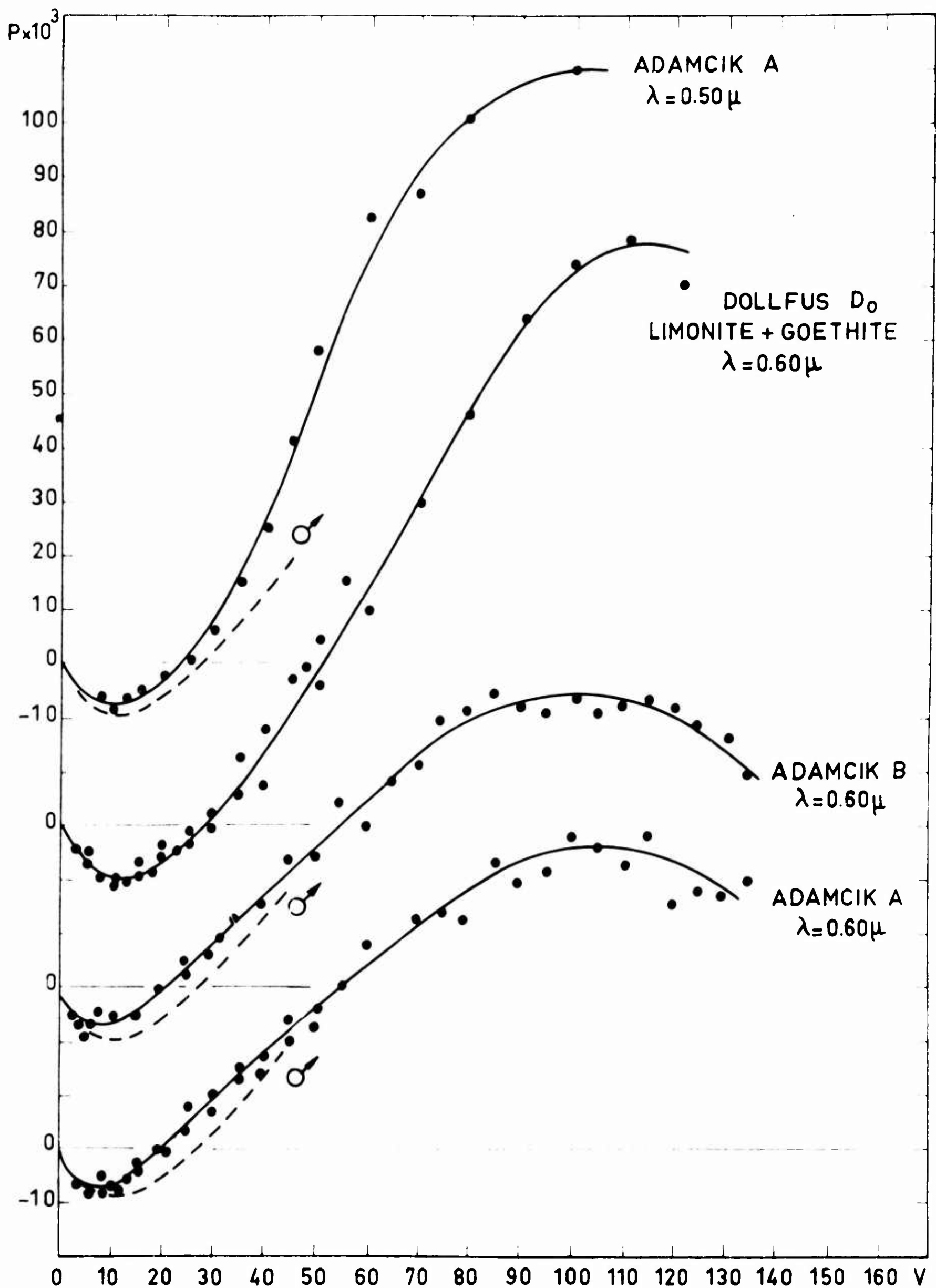
b) New investigations : We submitted the initial identification of limonite, obtained in 1951 polarimetrically, to a more accurate analysis, by studying simultaneously the polarimetric and photometric properties of samples and taking into account the more recent photometric and theoretical investigations. We received mineralogical samples of iron oxides and limonite from A. CAILLEUX (Laboratory of Geology, Sorbonne - Paris), V.V. SHARONOV (University Observatory of Leningrad), C. SAGAN (Harvard College Observatory). We received also samples of limonite artificially deposited on grains of silica and kaolin, from J. ADAMCIK (Texas Technological College). A large number of measures were taken in the laboratory by E. BOWELL in 1965 and 1966.

The polarization measures refer to the physical structure of the surface; the photometric measures as a function of the wavelength refer to the material of which the grains are made. The characteristic yellow aspect of the planet, corresponds to a very rapid change in the reflectivity of the soil of Mars in the visible part of the spectrum; this is fortunately a criterion of particular character, because the association of the polarization and the photometry allows the selection of specific samples which can define the Martian soil in an accurate manner.

c) Texture of the Martian soil :

The texture of the soil, its physical structure, is given by the







polarization. In 1950, we selected a sample of limonite-goethite which, pulverized in small grains, reproduced in a very satisfactory manner the polarization of the light of Mars in the visible part of the spectrum (3). The powder consisted of a complex mixture, smaller grains enwrapping larger ones as a superficial coating. The polarization curve of this sample  $D_0$  is given in Fig. 14.

In order to determine the size and texture of the grains, we sifted this sample to obtain two new powders, the first  $D_1$  consisting of large grains with sizes between 90 and 200 microns, and the second  $D_2$  of fine grains smaller than 40 microns. In Fig. 14 are reproduced the corresponding polarization curves. The negative parts of curves  $D_1$  and  $D_2$  are not identical with those of the planet Mars; the slopes of these curves beyond the angle of vision of  $30^\circ$  are too great. The curve  $D_2$  is closer to that of Mars than  $D_1$ ; this speaks in favour of the fine grains. But the best reproduction of the polarization of Mars is given by the sample  $D_0$  consisting of a blend of grains of any size smaller than 200 micron, in which the smaller wrap the larger.

If the deposit is compressed, or slightly squeezed, the minimum polarization becomes -6 thousandths instead of -10 thousandths, which is that measured on Mars. But the deposits of  $D_0$  which were strongly aerated in a complex non-squeezed structure, reproduce the polarization of the light of Mars in all its details.

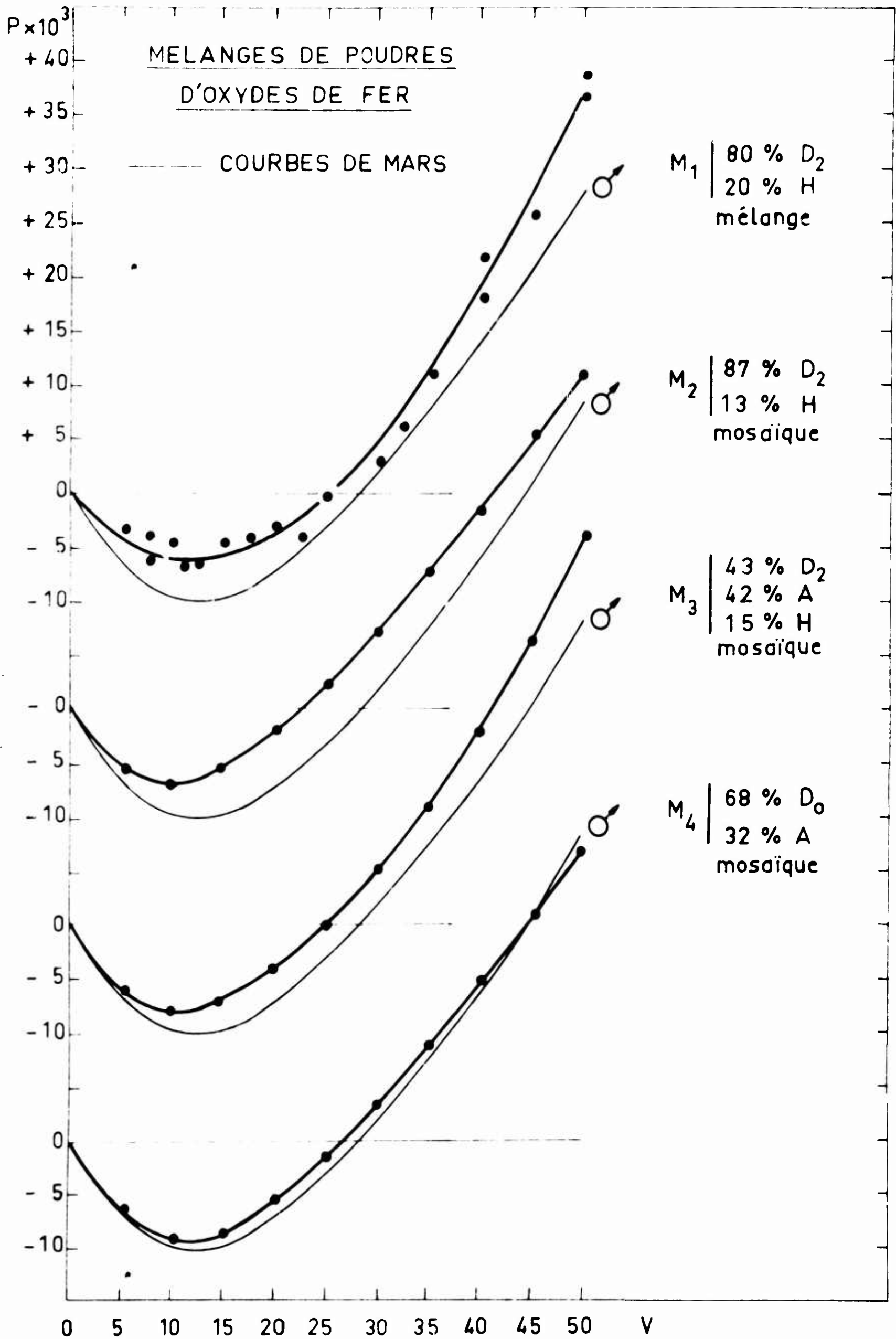
On the other hand, information about the structure of the soil of Mars on a scale larger than a few millimeters, is supplied by the photometric study of the reflecting power as a function of the directions of illumination and observation. These results have been published recently in another paper (27). Contrary to the case of the surface of the Moon, the soil of Mars is revealed as having only slight roughness. This might probably be explained by dust being transported by the wind and deposited as a uniform layer on the surface of the planet.

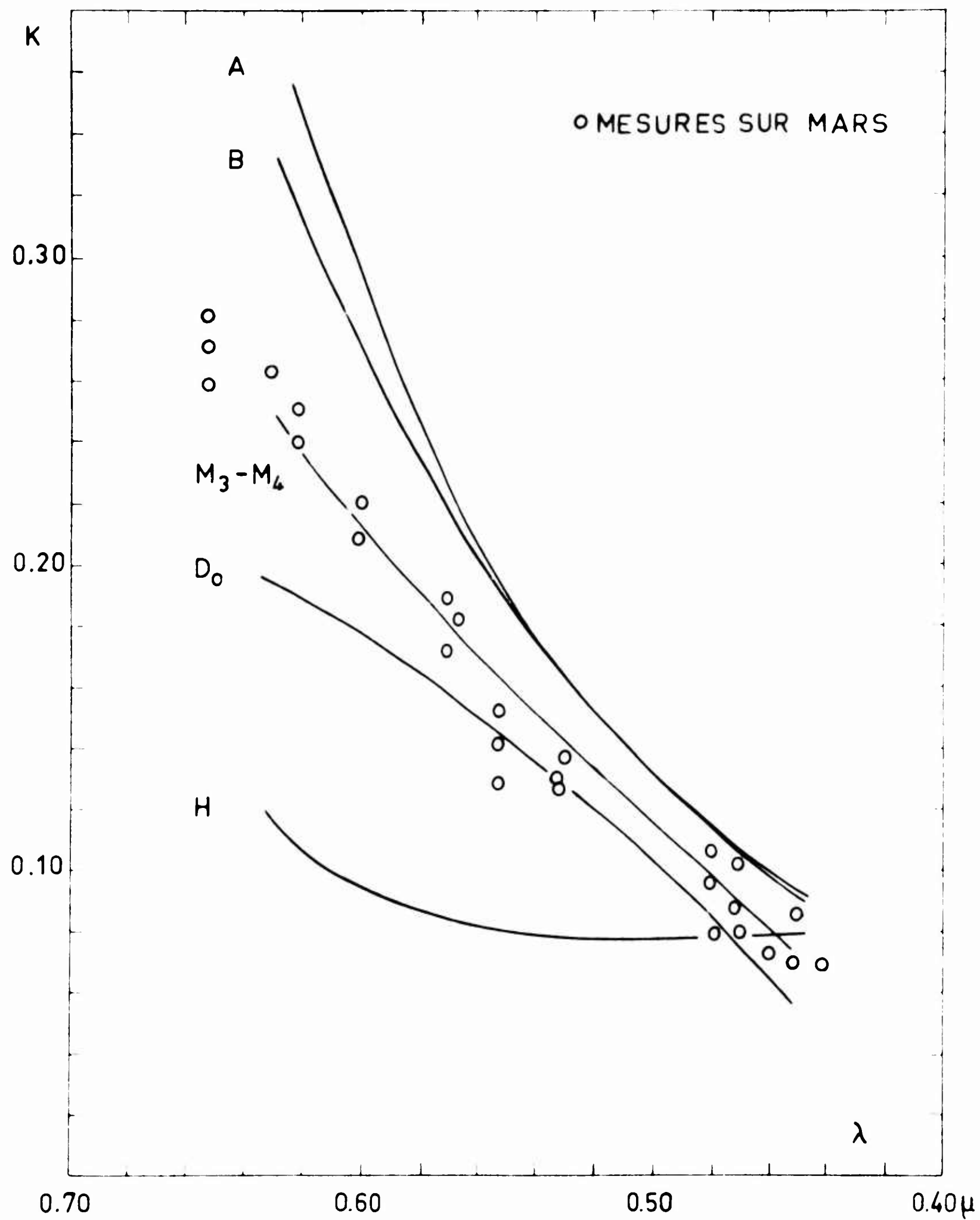
d) Composition of the constituent material :

The sample  $D_0$  gives a polarization similar to that of Mars, but two more difficulties still persist :

- The spectral variation of the reflectivity of the said substance . in the visible part of the spectrum does not reproduce exactly that of planet.
- The geological arguments raised by J. SALISBURY and his colleagues, indicate that pure limonites-goethites have little chance of existing on Mars; such a substance would preferably be present in the form of a superficial coating enwrapping grains of a different nature; this would probably be due to the action of atmospheric agents.

We studied the polarimetric and photometric properties of grains, artificially coated by a limonite deposit. J.A. ADAMCIK kindly supplied us with two samples, named A and B, having the following compositions : "Goethite ( $F_2O_3H_2O$ ) was deposited on silica ground to pass a screen with 62





micron openings, by hydrolysis of ferric nitrate. The material obtained contained 16 % goethite and is described as "16 % goethite on silice". Heating this material to 400°C dehydrated the goethite to hematite and gave the material described as "14 % hematite on silica". A similar procedure applied to kaolin gave "16 % goethite on kaolin" and "14 % hematite on kaolin". Then a basic mixture was prepared which contained : 9 parts (16 % goethite on silica), 3 parts (14 % hematite on silica), 3 parts (16 % goethite on kaolin) and 1 part (14 % hematite on kaolin). Then sample A was prepared by adding 0.65 % magnetite ( $\text{Fe}_3\text{O}_4$ ) to the basic mixture, and sample B by adding 22 % of hornblende (ground to pass a 62 micron screen) to another portion of the basic mixture".

The polarization curves of the samples A and B reproduced in Fig. 15 do not exactly fit the curves obtained from the planet; they seem to characterize transparent grains. The curves showing the variation of the reflecting power of the samples are reproduced in Fig. together with the photometric curves obtained from Mars. These curves are not identical; they exhibit great slopes, and the corresponding reflecting power is too high in the red. The agreement between photometric properties of the samples and those of the surface of Mars would probably be improved if the constituent material of the inner part of the grains of samples A and B were more opaque and absorbent.

Dr. E. BOWELL studied in our laboratory at the Meudon Observatory, new mixtures with compositions ranging between those of the samples A, B and D as well as a powder of pulverized hematite H (see Fig. 16 and 17). Two types of associations are considered : a) direct mixture of grains of different constituents, b) juxtaposition of the different constituents in the form of a mosaic. In the first case, the measures were taken directly in the laboratory; in the second case, the resulting reflecting power is calculated by formula :

$$K = \frac{\sum K_i Q_i}{\sum Q_i} \quad \text{and} \quad P = \frac{\sum P_i K_i Q_i}{\sum K_i Q_i}$$

$Q_i$  = Proportion (in %) of each constituent, i

$K_i$  = Reflecting power of each constituent, i

$P_i$  = Polarization of each constituent, i

Four mixtures reproduce well the spectral reflectivity of Mars :

$M_1$  = 80 %  $D_2$  , 20 % H (mixture of grains)

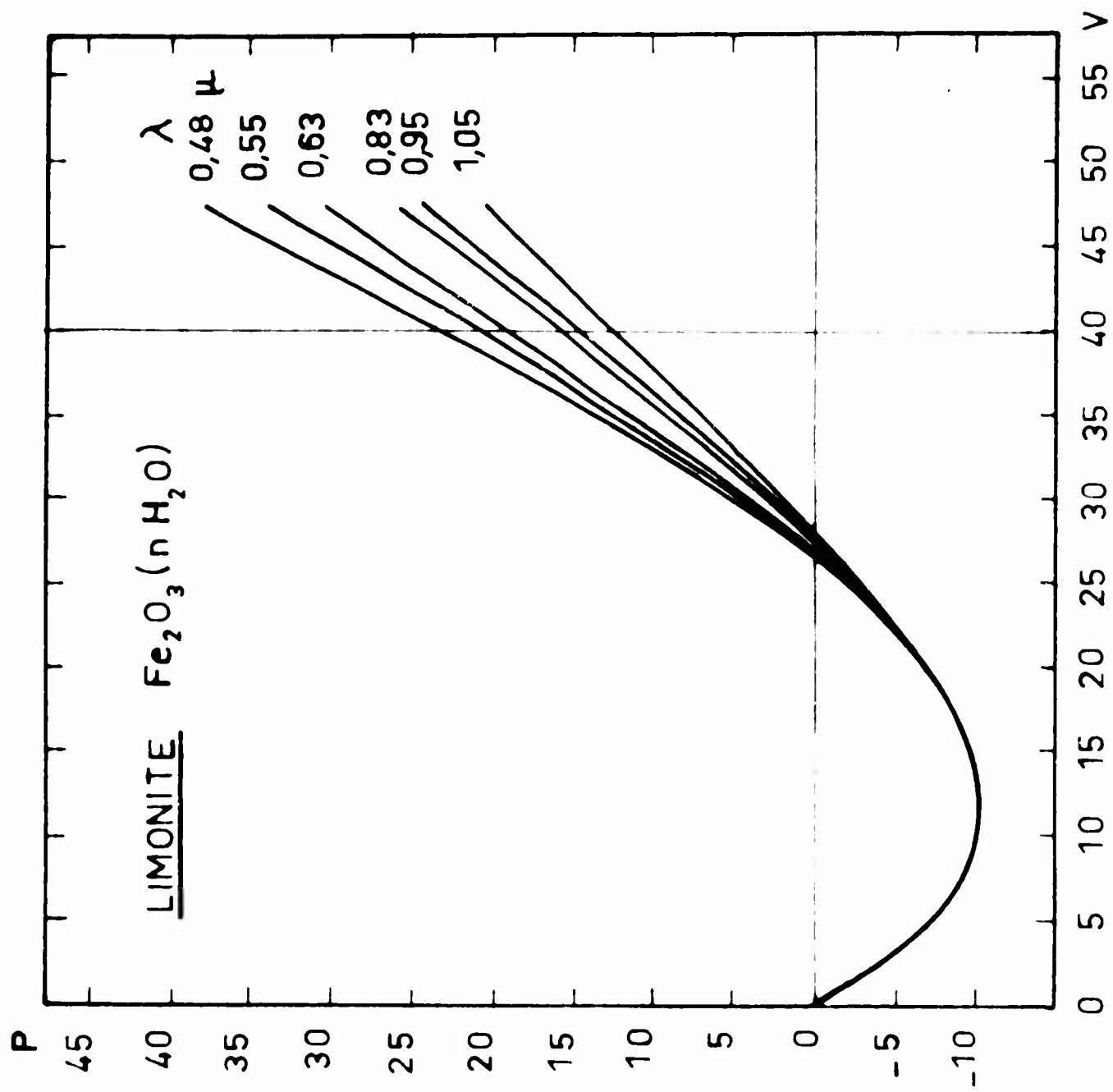
$M_2$  = 87 %  $D_2$  , 13 % H (mosaic)

$M_3$  = 43 %  $D_2$  , 42 % A, 15 % H (mosaic)

$M_4$  = 68 %  $D_0$  , 32 % A (mosaic)

The polarization curves are reproduced in Fig. 17. The sample  $M_4$  reproduces the polarization of the light of Mars to 1 or 2 thousandths approximately. The relative photometric curve is identical to that resulting from measures taken on Mars. Moreover, this mixture reproduces the polarization of the light of Mars in the Infra-red (Fig. 18) because the negative





branch of the polarization curve of the planet in the Infra-red is independent from the wavelength (Fig. 4).

The mixture  $M_4$  corresponds to the juxtaposition of grains of pure limonite-goethite and of grains of silica and kaolin coated by a superficial deposit of limonite.

Naturally, the composition of the mixture is not a critical one. Various mixtures of grains consisting of absorbent materials, the surface of which is completely coated with limonite or goethite, should reproduce satisfactorily the polarimetric and photometric properties of the soil of Mars.

c) Conclusion :

The surface of the soil of the ochre coloured desertic bright areas of Mars is similar to a mixture of fine grains of any size, wrapping each other and forming a sufficiently aerated deposit of a low roughness. The grains consist of limonite, or a pulverized absorbent and opaque material with the surface of the grains coated by a deposit of hydrated iron oxide of the "limonite" type.

SURVEY OF THE POLARIMETRIC MEASUREMENTS OF THE DARK AREAS OF MARS SINCE 1948 :

The dark areas of the surface of Mars show a polarization slightly different from that of bright desertic areas.

The measures taken on the dark areas during the last nine apparitions of Mars since 1948, enabled us to trace their polarization curves reproduced in Fig. 19 to 27. We classified these areas into 3 groups : southern, equatorial and northern. The proportion of polarized light  $P$ , was plotted, for each apparition, against the angle of vision; the figures, moreover, show the heliocentric longitude of the planet, which characterizes the Martian season.

In 1948, Fig. 19, the northern hemisphere of the planet was in spring and the southern in fall. The dark areas of each hemisphere give polarimetric curves different from those of the other.

In 1950, Fig. 20, by starting summer of the northern hemisphere, discrepancies between the polarization of the southern and northern dark areas still persist.

Measures taken in 1952, Fig. 21, correspond to the end of the summer and the start of the fall; the polarization curves of the dark areas of the two hemispheres become almost alike.

In 1954, Fig. 22, the fall is over; the polarimetric curves of all the dark areas are identical.

In 1956, the measurements before opposition were disturbed by yellow veils in the Martian atmosphere. After opposition, the northern hemisphere of the planet was in winter; the detailed study of the individual dark spots seen between the veils shows discrepancies with stronger negative polarization on the southern spots.

In 1958, Fig. 24, the Martian atmosphere was practically free from veils before opposition. The southern hemisphere was in middle summer; the polarization of the spots of the two hemispheres shows but a slight difference.

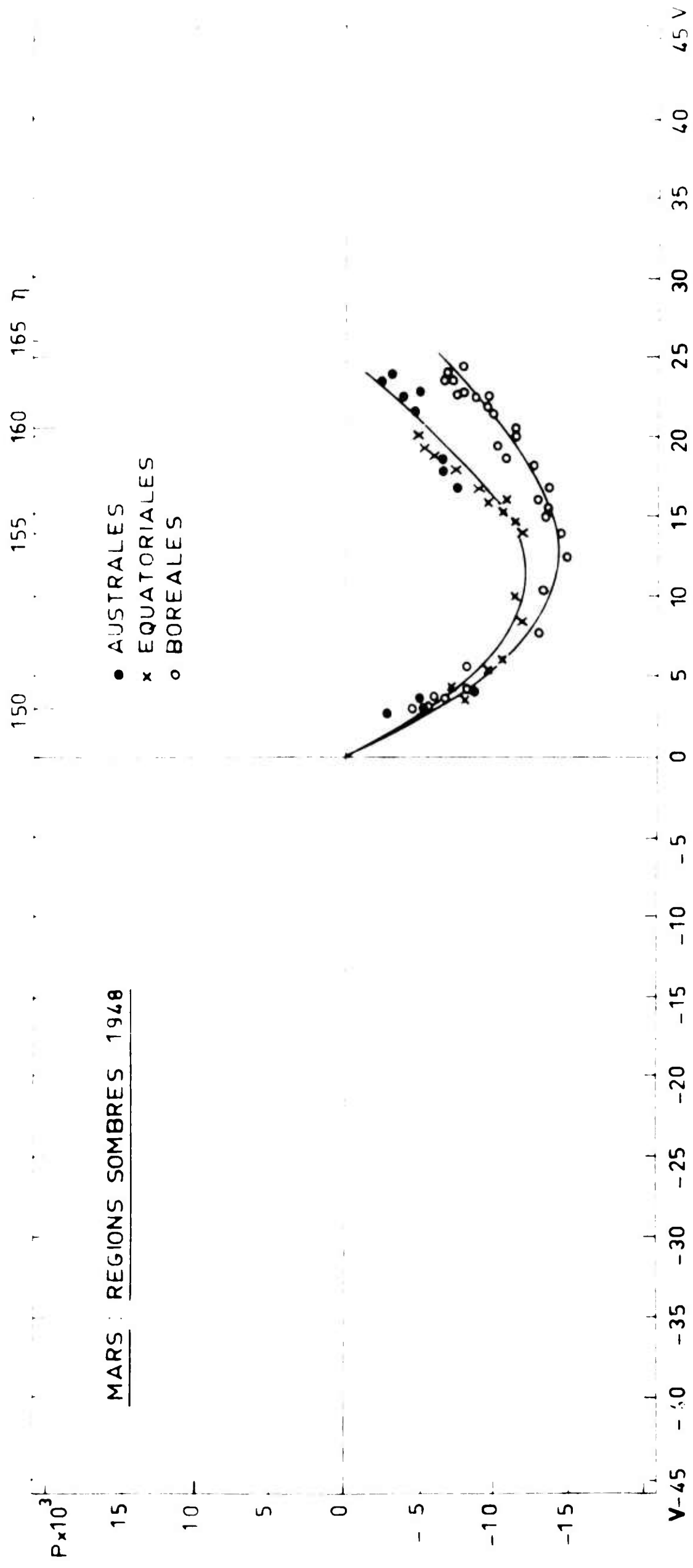
In 1961, Fig. 25, the second part of the apparition corresponds to the start of the northern spring with the dark spots showing again a weaker polarization than those in the south.

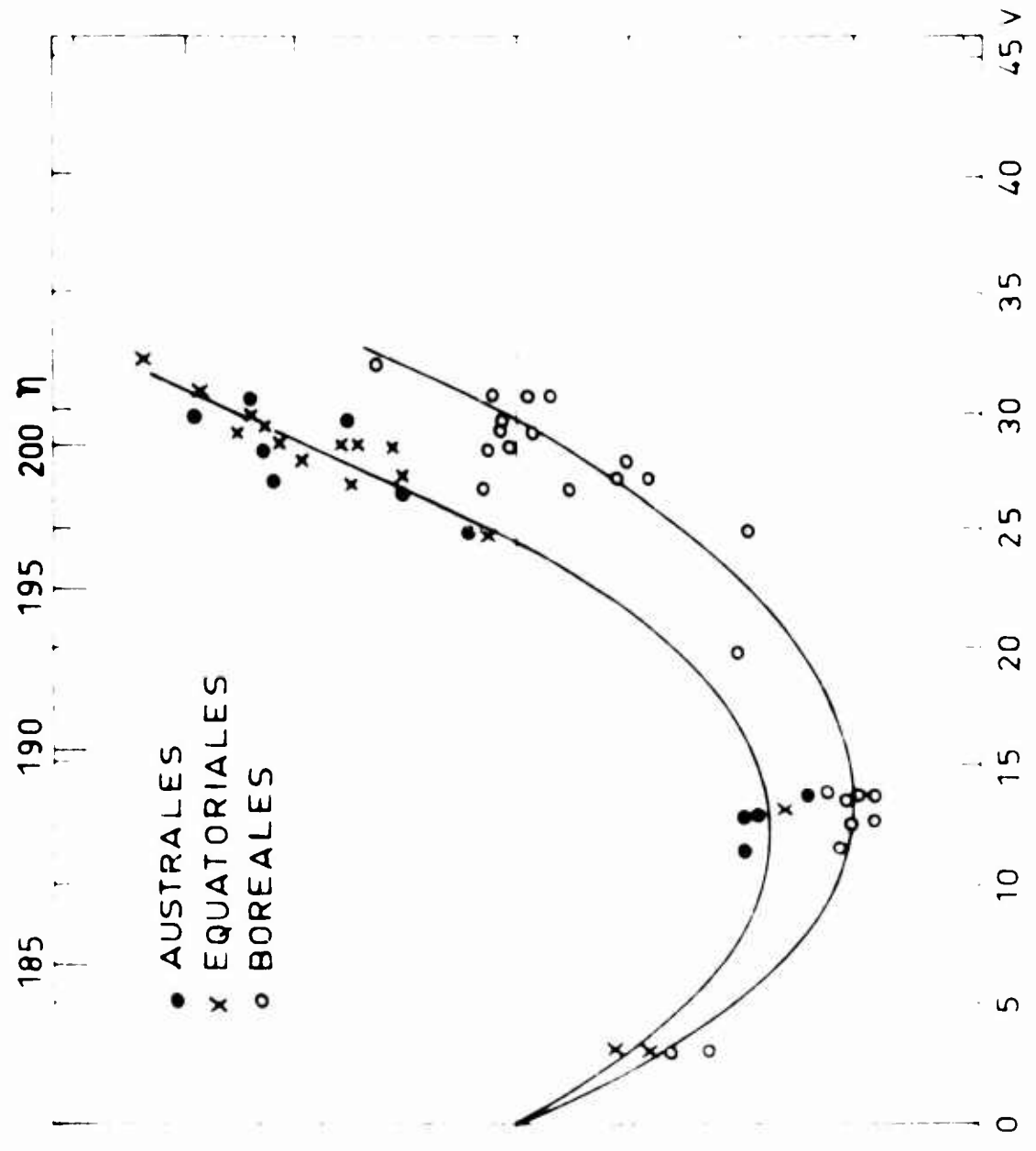
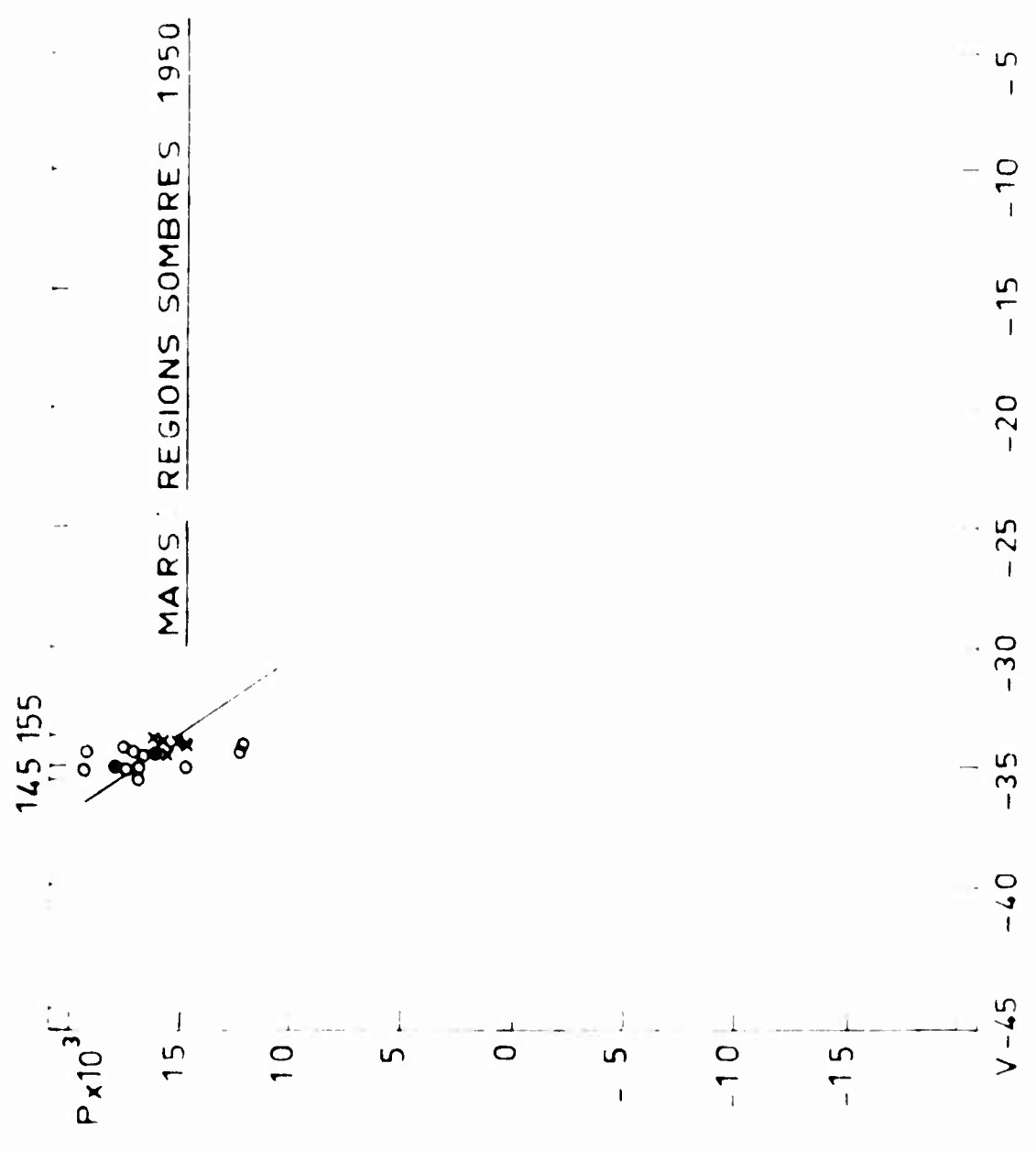
In 1963, Fig. 26, the planet was in almost similar seasonal conditions as in 1961; the slight difference in the polarization of the dark spots in the two hemispheres persists. After opposition, the northern hemisphere of the planet is in middle spring, but veils in the Martian atmosphere disturb the measurements.

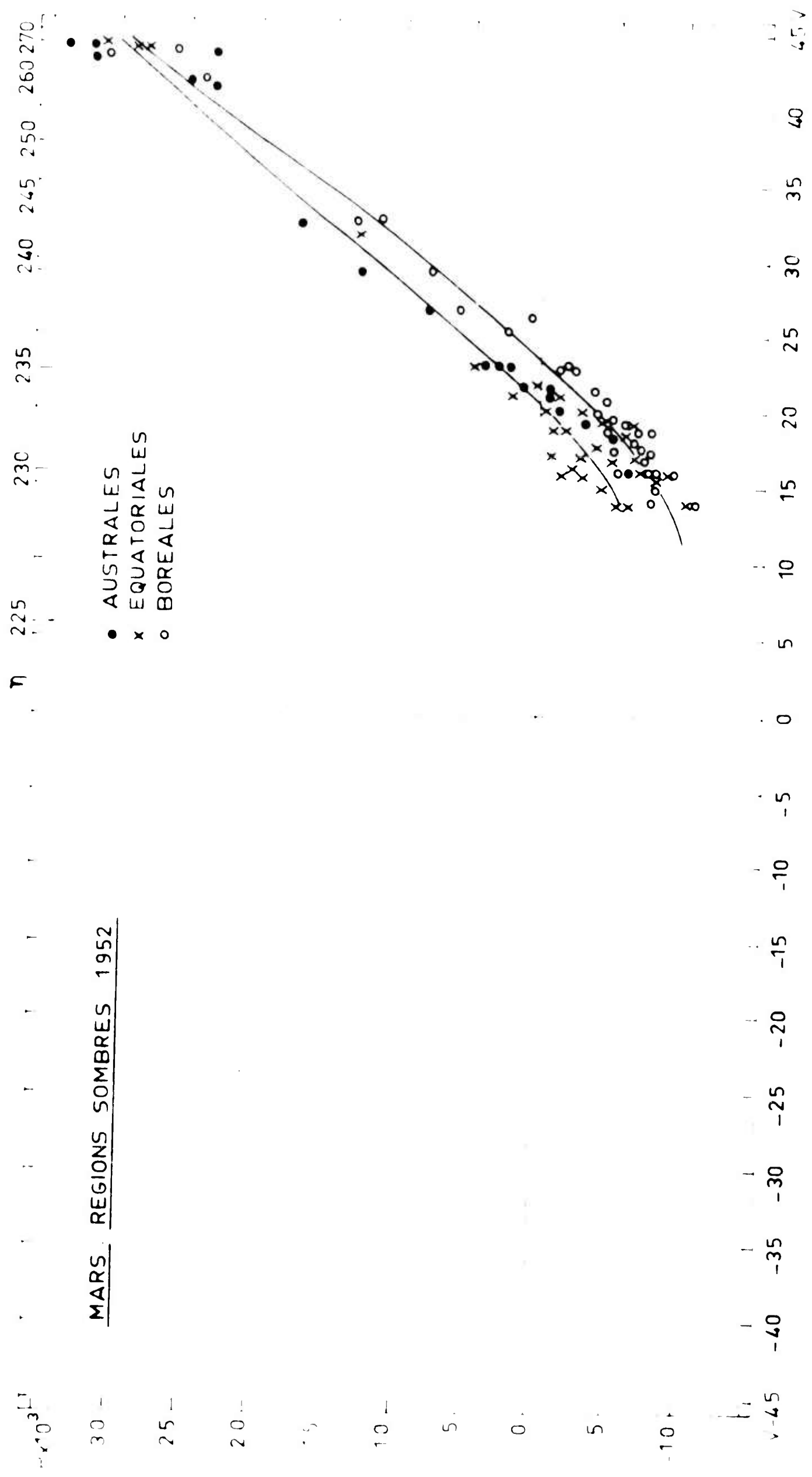
Finally, in 1965, Fig. 27, the first part of the curve corresponds to the middle of spring of the northern hemisphere, in which the dark spots show a stronger negative polarization than those of the southern hemisphere, this was observed in 1948 during the equivalent season.

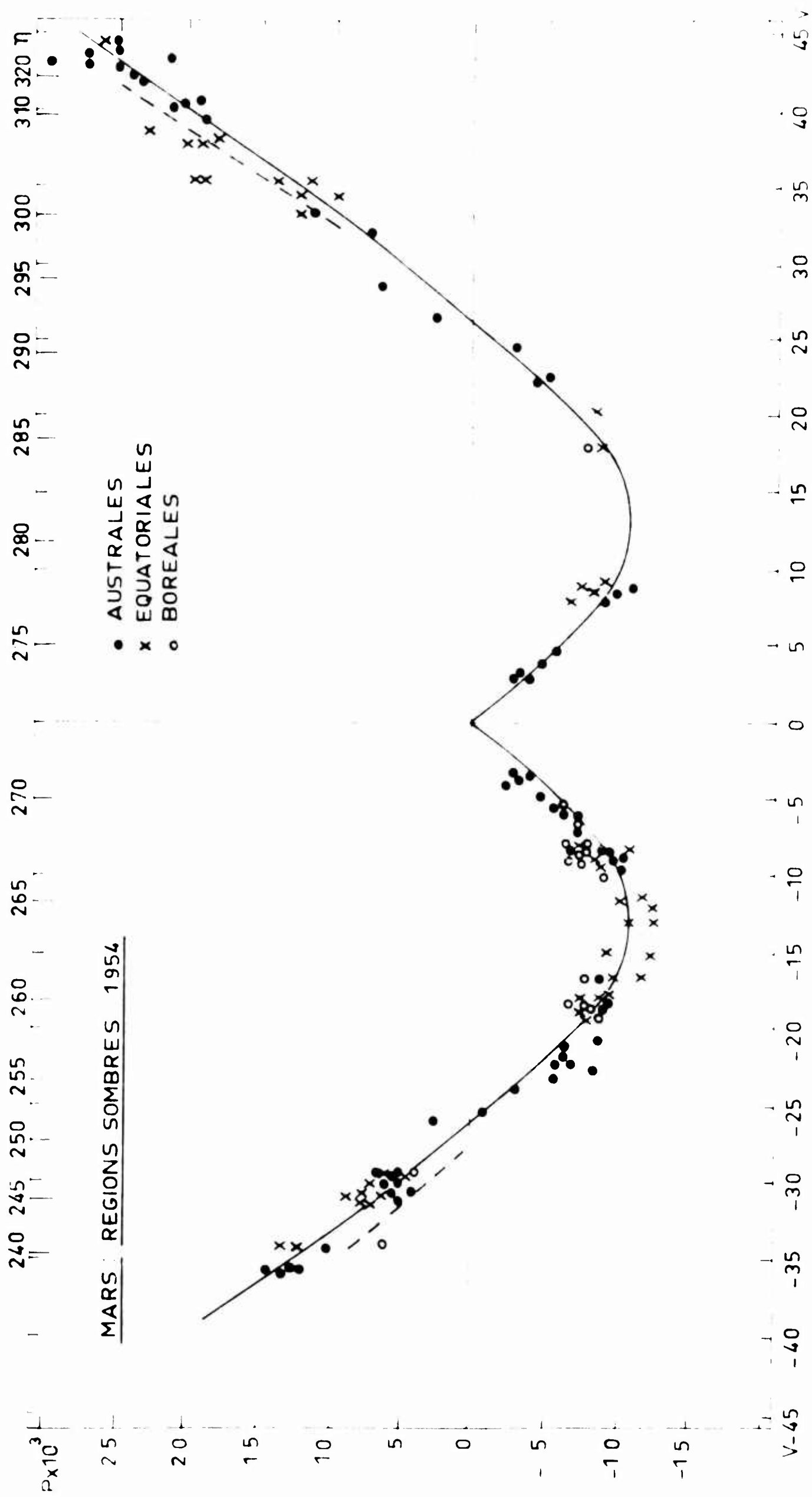
Our observations refer to a period of 18 years and cover a complete Martian seasonal cycle.

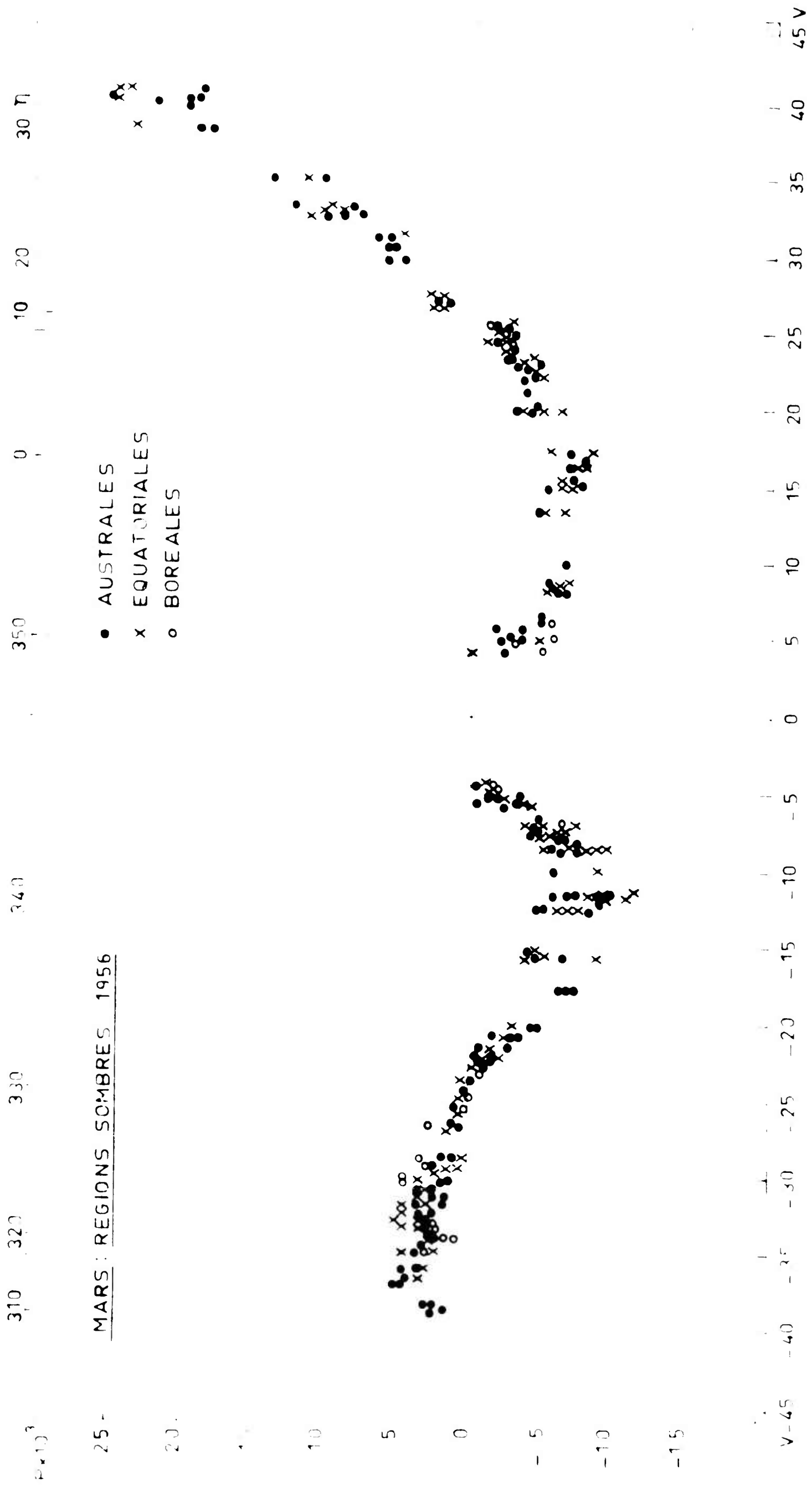
It results from the above, that the dark spots of the surface of Mars show a seasonal variation of polarization manifested during the Martian spring.



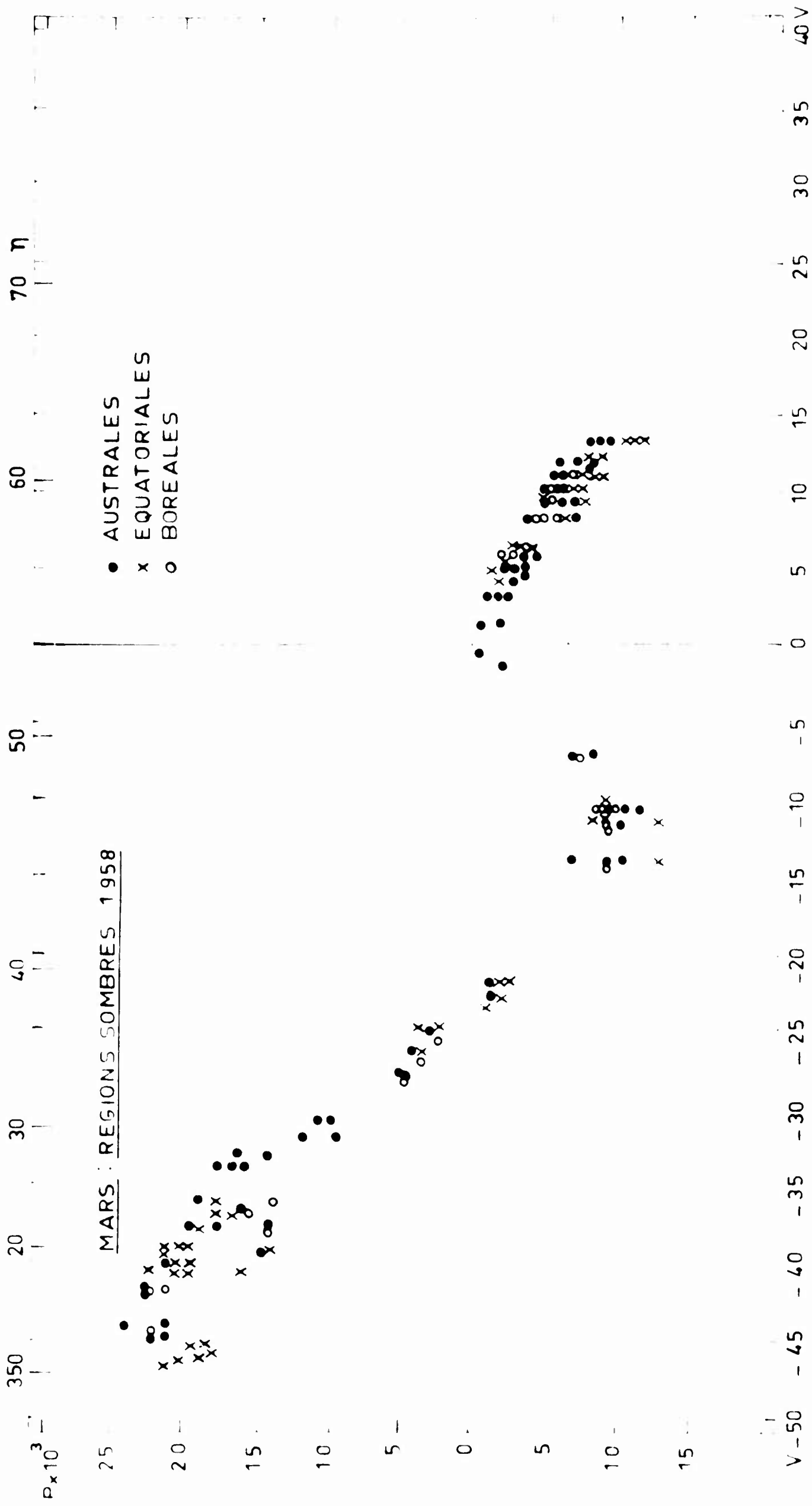


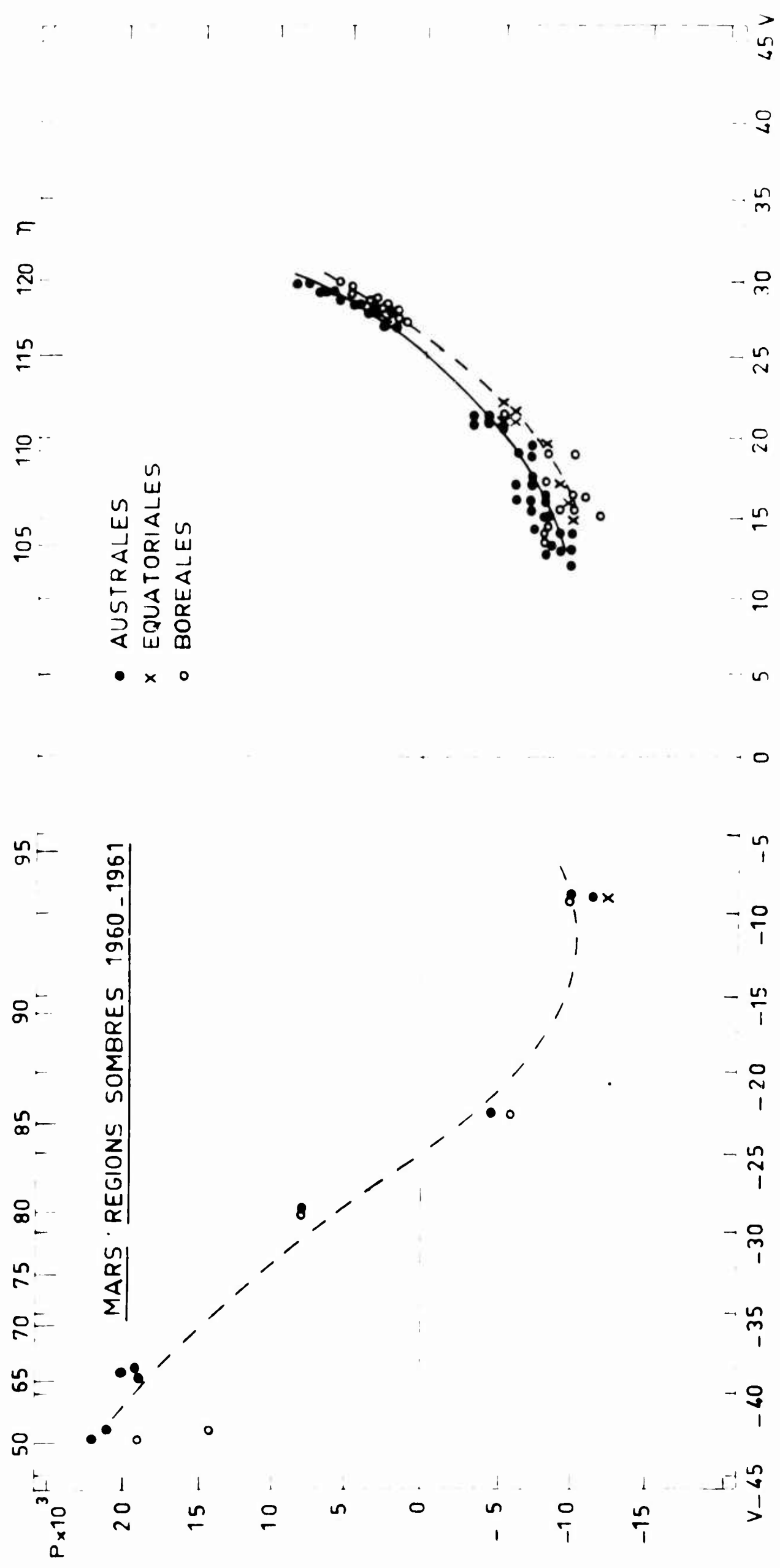


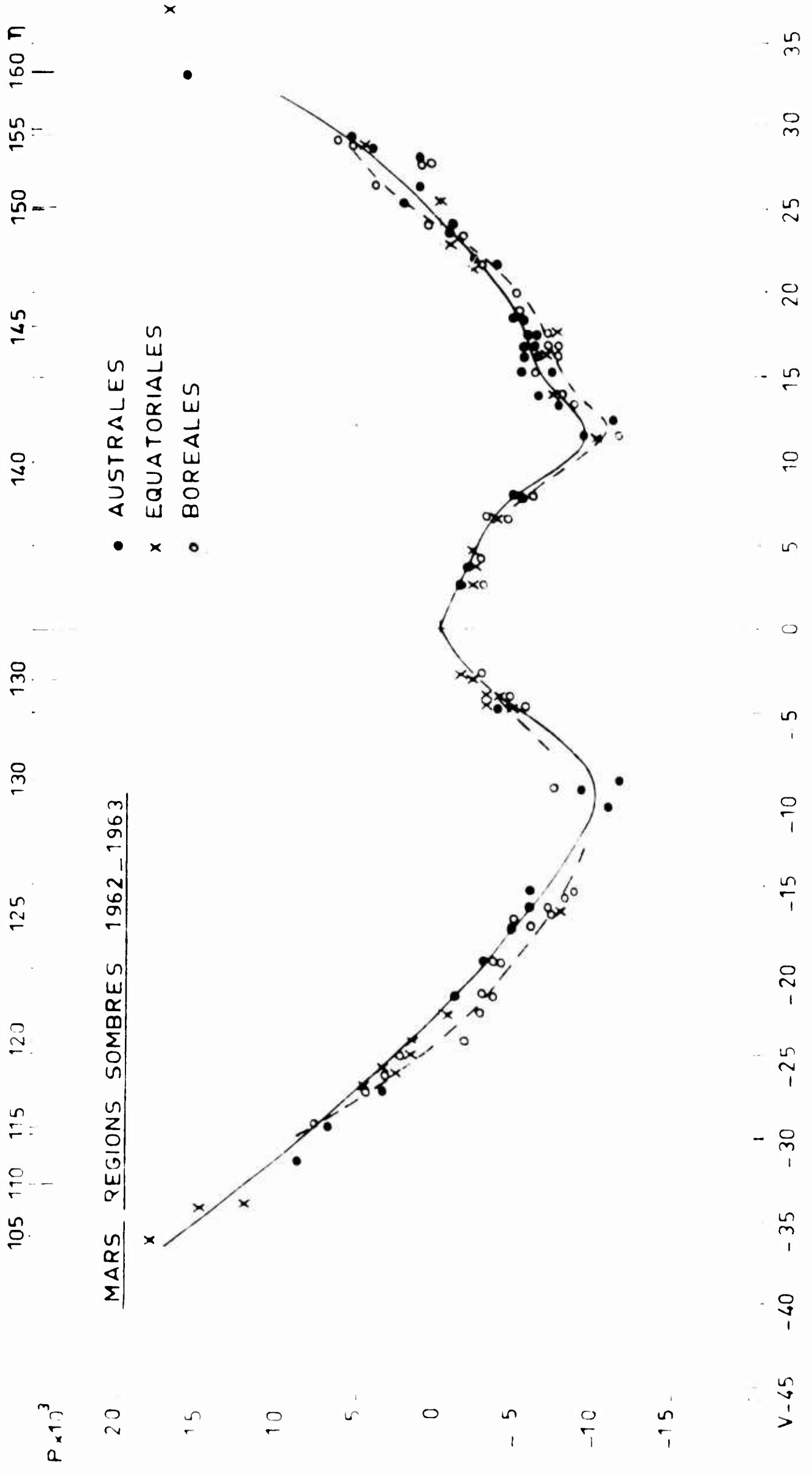


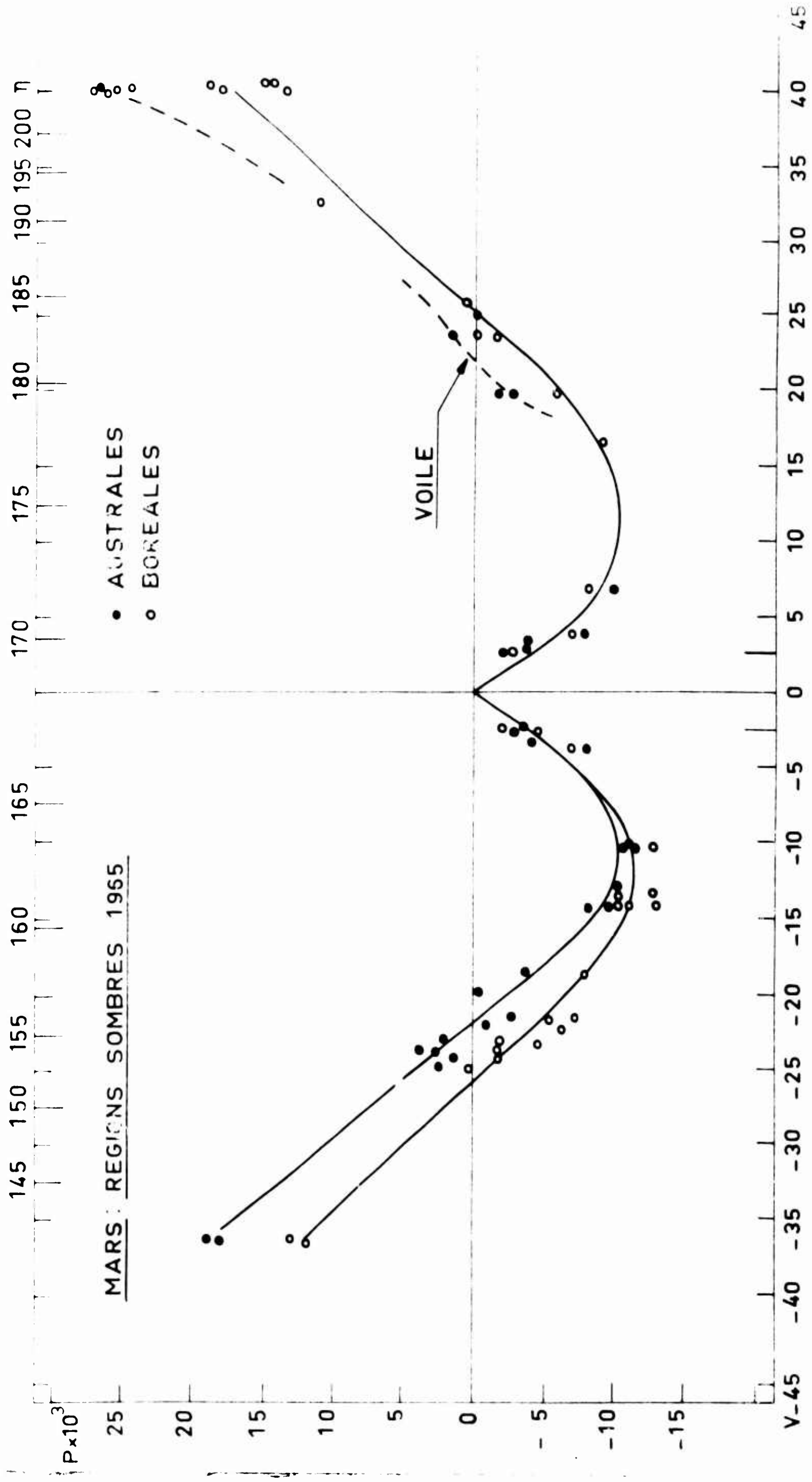












During this season, the polarization becomes stronger in the negative sense. In order to study this seasonal variation, we selected the measures corresponding to the phase angle of  $25^\circ$ .

Table N° 5 shows for each observational year :

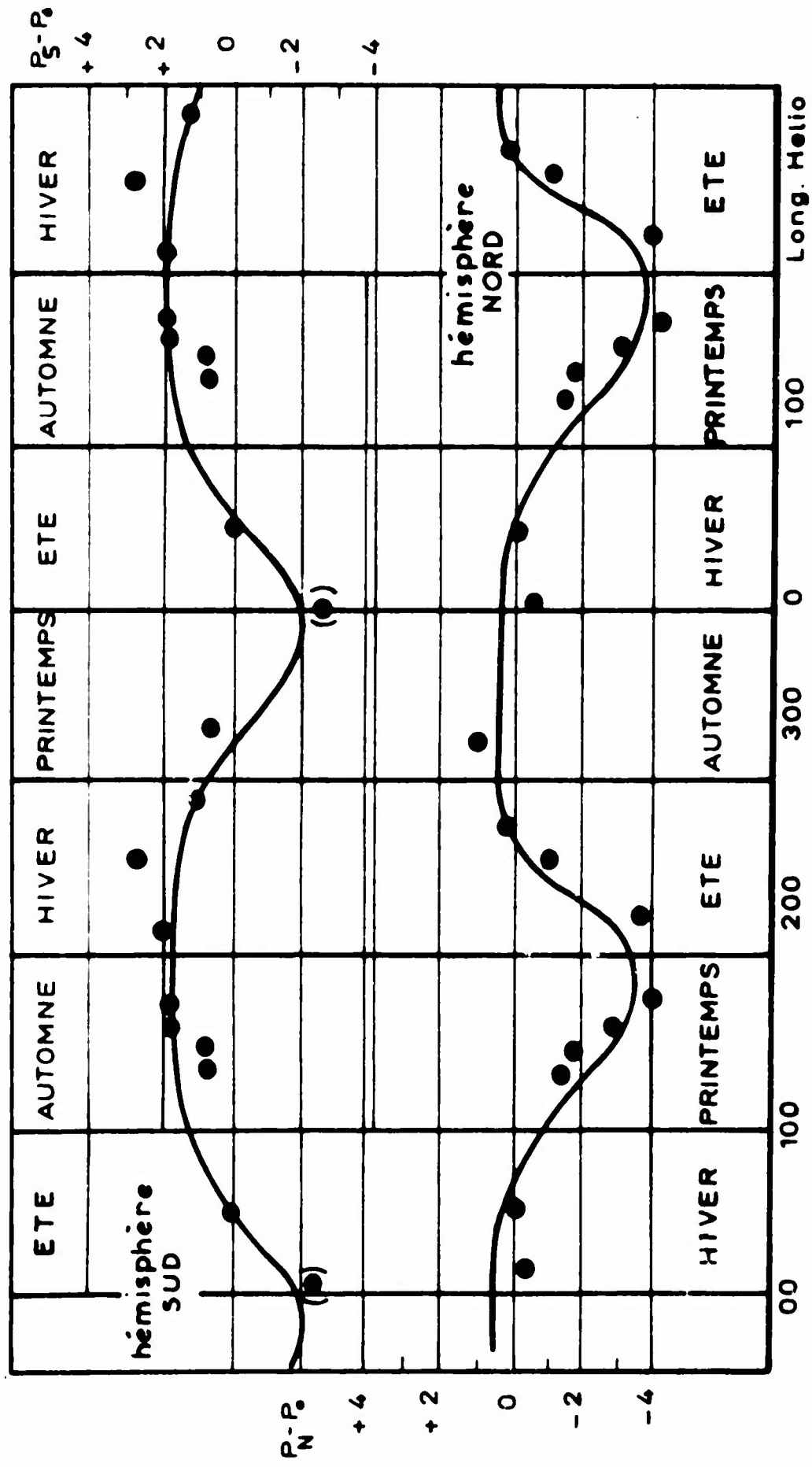
- the heliocentric longitude of the planet for the phase angle of  $25^\circ$ .
- The difference  $P_N - P_S$  between the polarization of the northern and the southern dark spots, for the phase angle of  $25^\circ$ .
- The difference  $P_N - P_0$  between the polarization of the northern dark spots and that of the neighbouring bright areas.
- The difference  $P_S - P_0$  between the polarization of the southern dark spots and that of the neighbouring bright areas.

TABLE III

Year	Helico. Longit.	$P_N - P_S$ ‰	$P_N - P_0$ ‰	$P_S - P_0$ ‰
1948	I64	- 6	- 4	+ 2
1950	I97	- 6	- 4	+ 2
1952	257	- 4	- 1	+ 3
1954	253	- 1	0	+ 1
1954	291	0	+ 1	+ 1
1956	8	+ 2	- 0,5	- 2,5
1958	36	0	0	0
1961	II5	- 2	- 1,5	+ 0,5
1963	II9	- 2,5	- 2	+ 0,5
1965	I57	- 5	- 3	+ 2

The cycle of the seasonal variation of the polarization of the dark areas of Mars is given by Fig. 28, resulting from the data of Table 3. Abscissae represent the heliocentric longitudes and the limits of the seasons for the two hemispheres of the planet; Ordinates represent  $P_N - P_0$  and  $P_S - P_0$ . The differences of polarization are maxima at the end of the spring and occur principally during spring and summer of each hemisphere.

It is known (I2) that the dark areas of the surface of Mars show variations of their intensity which seem to propagate, with the season, from the poles towards the Equator, during the spring and summer of each hemisphere of the planet. It is clear that the seasonal variation of the polarization of the dark areas is associated with the seasonal variation of their intensity.



In view of the fact that the polarization of the light characterizes the contexture of the surface in a microscopic scale, it should be admitted that the darkening of the dark areas in spring is associated with a change of their microscopic contexture.

This verification, based now on polarimeter observations extending over an 18 year period, confirms the preliminary results, pointed out in 1955 (3).



DETERMINATION OF THE SCATTERING COEFFICIENT OF THE ATMOSPHERE OF MARS IN 0.61 MICRON

The polarimetric measures collected during the apparition of Mars in 1948 and 1950, completed to a certain extent by measures taken in 1952, allowed a preliminary determination of the quantity of light scattered by the atmosphere of the planet ( 28 ). Such a determination was based on the measures made on the bright areas of Mars. The luminance of the Martian atmosphere for its whole depth at the center of the disc, at zero phase, has been estimated to be 0,023 stilb at 1 astronomical unit from the Sun, for  $\lambda = 0,61$  micron. The corresponding diffusion factor amounts to 0.0017 stilb/phot. If the atmosphere was completely free from aerosols, the atmospheric pressure of the ground, necessary to give such a brightness should be of the order of 80 to 90 millibars. However, this first determination was based on 14 polarimetric sequences only ; they have been combined with some very preliminary photometric measures, the only available at the time ; moreover, at that epoch, we could not know in detail the pollution properties of the Martian atmosphere.

Recently, L.W.P. CANN ( 29 ) revised this value by using the same polarimetric measures, combined with more accurate photometric measures published by A. DOLLFUS in 1956 ( 30 ). This revision gave 0.013 stilb at unit distance from the Sun ; this value corresponds, for a very clear atmosphere, to a pressure on the ground of the planet, of approximately 50 millibars only.

The great number of polarimetric measures, previously summarized, allows now a very responsive improvement of these preliminary determinations. Among the 5,200 measures of polarization taken during the last 13 years in yellow light on the bright areas of the planet, we selected these corresponding to periods in which the Martian atmosphere has been considered to be particularly free from aerosols (See Fig. 8 to 13) ; moreover, the analysis of the visual and detailed study of the repartition of the polarized light at the disc's limb, allowed a second selection of observations among those of the first selection (see for example Fig.1.) for the elimination of local haze or temporary atmospheric pollutions. Finally, observations secured in 45 nights only have been retained ; these observations characterize the period in which the martian atmosphere was of a particular limpidity. These observational sequences give the proportion of polarized light  $P(\vartheta)$  of the uniform bright areas of the soil of Mars, for different distances from the center of the disc in a direction perpendicular to the line joining the cusps.

If  $P(0^\circ)$  represents the polarization observed at the center of the disc for  $\vartheta = 0$ , we establish the differences  $P(\vartheta) - P(0^\circ)$  between the measures taken at the disc's limb and the center. We obtain such data for different values of the phase angle  $V$ .

We consider  $B_a(v, \theta)$  to be the luminance of the martian atmosphere observed through its whole depth, at the distance  $\theta$  from the disc's center, for the phase angle  $V$ .  $B_s(V, \theta)$  is the luminance of the bright areas of the soil of Mars for  $\lambda = 0.61$  micron the values of  $B_s$  are given by the photometric measures collected by A. DOLLFUS in 1950 and 1952 which are summarized in the left figure of plate.  $P_s(\theta)$  be the difference of polarization given by the soil at the center of the disc for the inclination  $\theta$  this quantity  $P_s$  is small and was determined through measurements carried out in laboratory on samples having the same properties than the soil of Mars the values of  $P_s(\theta)$  are given as a function of  $\theta$  by the upper curve of Fig. 29

Let  $B_a(V)$  and  $P_a(V)$  be the luminance and the polarization given by the atmosphere of Mars at the center of the disc.

$$\text{We have } B_a(V, \theta) = \frac{B_a(V, 0)}{\cos \theta}$$

We admit now that, due to their selection, the measures refer to areas where the atmosphere is composed of molecules or particles smaller than the wave length, diffusing the light as the molecules

$$B_a(V, \theta) = B_a(0, 0) \times \frac{1 + \cos^2 V}{2 \cos \theta} \quad \text{and} \quad P_a(V) = \frac{\sin^2 V}{1 + \cos^2 V}$$

The polarization of the soil and that of the atmosphere are combined (3) and give :

$$P(V, \theta) = P_s(V) + P_s(\theta) + \frac{B_a(0, 0)}{B_s(V, \theta)} \times \frac{\sin V}{2 \cos \theta}$$

The difference between the measures taken at the limb and the center of the disc, give :

$$P(\theta) - P(0) = P_s(0) = \frac{B_a(0, 0)}{B_s(0, 0)} \times \frac{\sin^2 V}{2} \left[ \frac{B_s(0, 0)}{B_s(V, 0)} - \frac{1}{\cos^2 \theta} \frac{B_s(0, 0)}{B_s(V, 0)} \right]$$

or  $Y = \frac{B_a}{B_s} X$

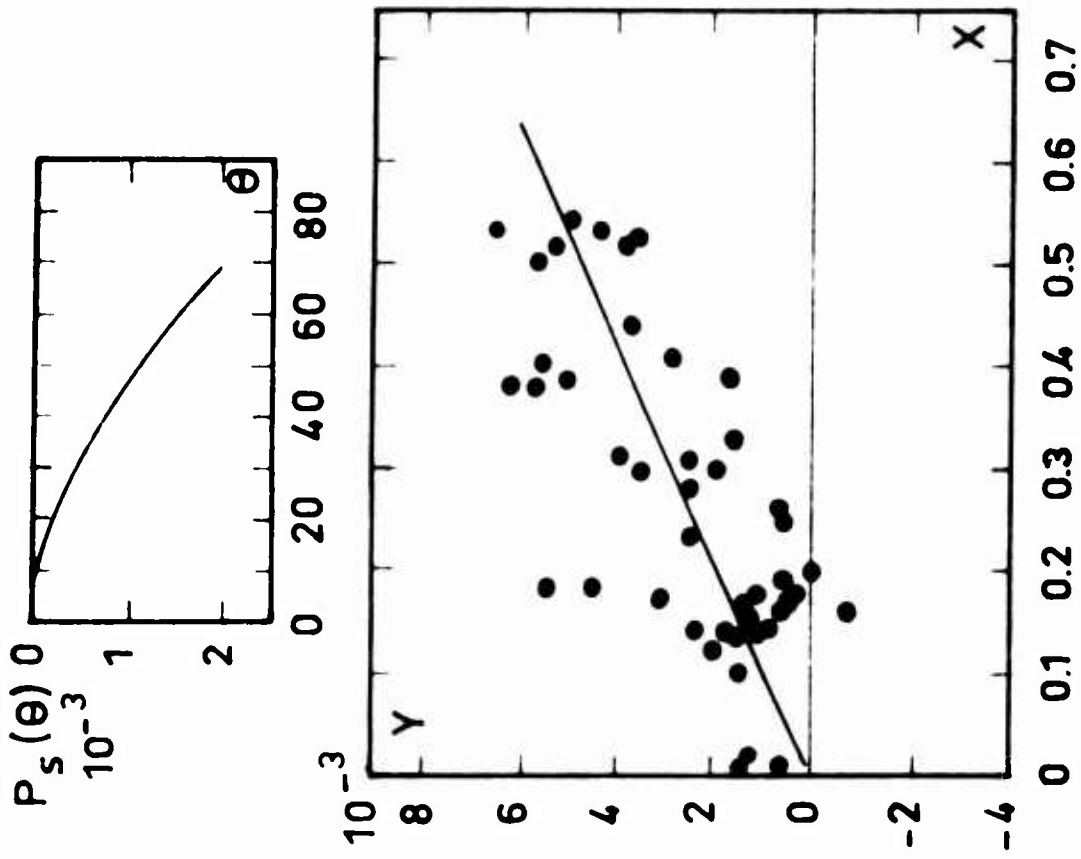
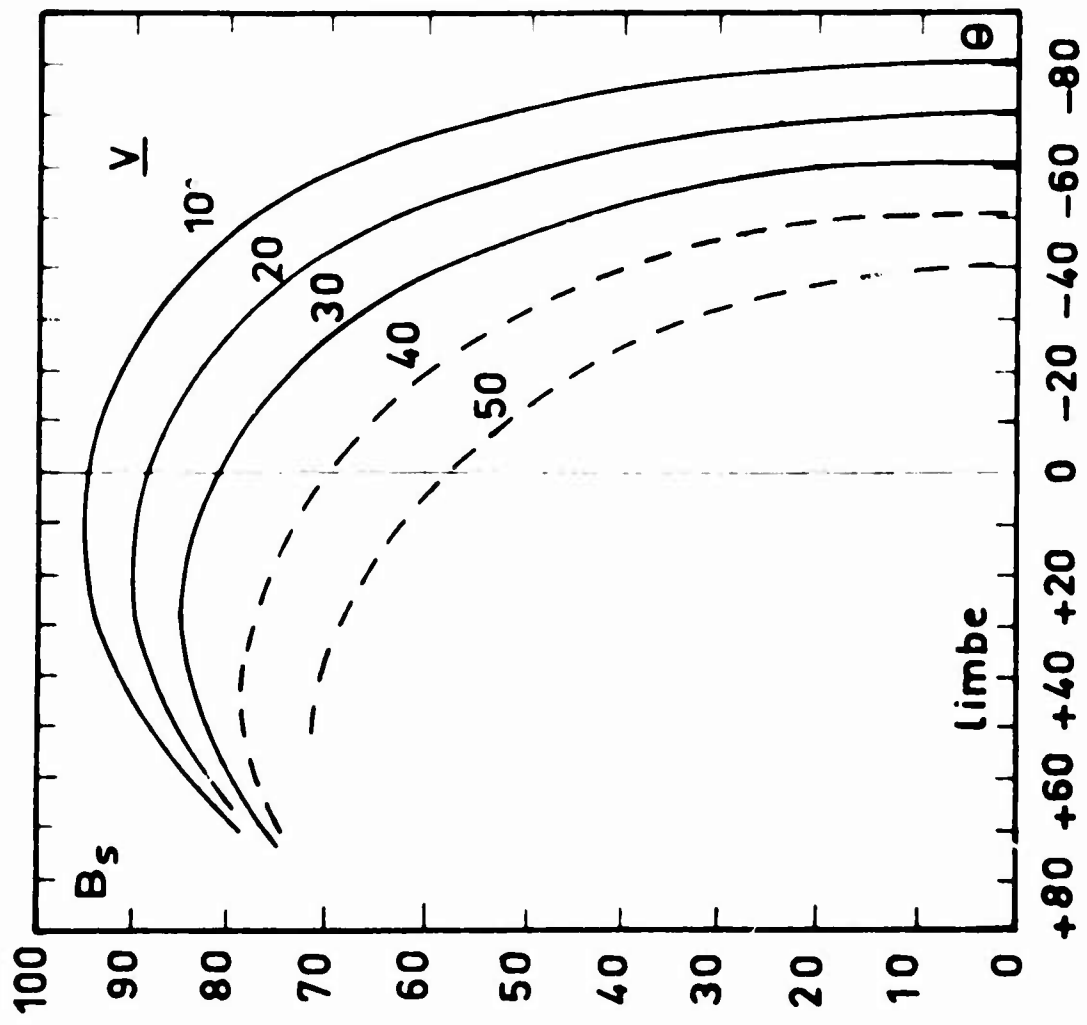
$\frac{B_a(0, 0)}{B_s(0, V)}$  and  $P_s(\theta)$  are given by Fig. 29 and Fig.

$P(0) - P(0)$  are given by the observations.

On fig. 29 the measures, on the whole, define a straight line the slope of which determines  $\frac{B_a}{B_s} = 10,0 \times 10^{-3}$ , at the true oppositer

for the bright areas at the center of the disc and for  $\lambda = 0,61$  micron

The photometric measures (30) give  $B_a = 0,35$  stilb at 0.52 A.U. from the sun. The illumination given by the Sun at unit distance is  $13,5$  pho. Consequently, the global scattering power of a vertical column of air at the center of the disc of the planet, at null phase in orange light 0.61 micron, under the best observing conditions, of atmospheric transparency on Mars amounts to :  $K_a(0.61 \text{ micron}) = 10 \cdot 10^{-3} \times 0.35 \times (1,52)^2 \frac{1}{13,5} = 6,0 \cdot 10^{-4}$  stilb/pho



Suppose the atmosphere of the planet really pure containing only molecules, for example of nitrogen, the scattering power of which amounts - under the normal conditions of pressure and temperature and layer depth - to  $h$  cm :  $K_{N_2} = 2 Rh$ . ( $R$  = Rayleigh's constant =  $4.3 \times 10^{-9}$ ). The depth of the Martian atmosphere, under normal conditions, should, therefore be :  $7.10^6$  cm and the atmospheric pressure on the ground approx. 30 millibars.

# DETERMINATION OF THE SCATTERING OF THE ATMOSPHERE OF MARS AT 0.47 MICRON :

The polarimetric measures allow still the determination of the luminance of the Martian atmosphere in blue light. Fig. 6 and 7 give the polarization of the light at the center of the disc by maximum phase angle  $V = 39^{\circ}29'$  in 1965. The curves express the slow variation of the polarization as a function of the phase angle  $V$ . During certain periods (end of June and start of July 1965), the discrepancies between the measures indicated the presence of thin veils of ice crystals in the Martian atmosphere. Number of measures do not seem to be affected by veils. Those selected for the phase angles between  $39^{\circ}26'$  and the maximum value of  $39^{\circ}29'$  are reported on Fig. 30 as a function of the inverse of the wave length; they give the curve of the spectral variation of the polarization for the average phase angle  $V = 39^{\circ}28'$  when the Martian atmosphere is clear. This curve can be compared with the measures taken in laboratory, for the same phase angle, on samples of pulverized limonite and goethite, which reproduce the polarization of the light given by the martian soil (Fig. I4 to I8). In the Infra-red, the polarizations recorded on Mars and the samples are very close; the light scattered by the interposed Martian atmosphere is practically negligible. Towards the blue, the curves diverge; the discrepancy is to be attributed to the atmosphere above the soil of Mars; the brightness of the atmosphere increases rapidly with decreasing wavelength; the difference amounts to  $\Delta P : 23$  thousandths for  $\lambda = 0.47$  micron.

Let us suppose that the Martian atmosphere, free from discernible impurities, polarizes the light as the molecules of a pure gas :

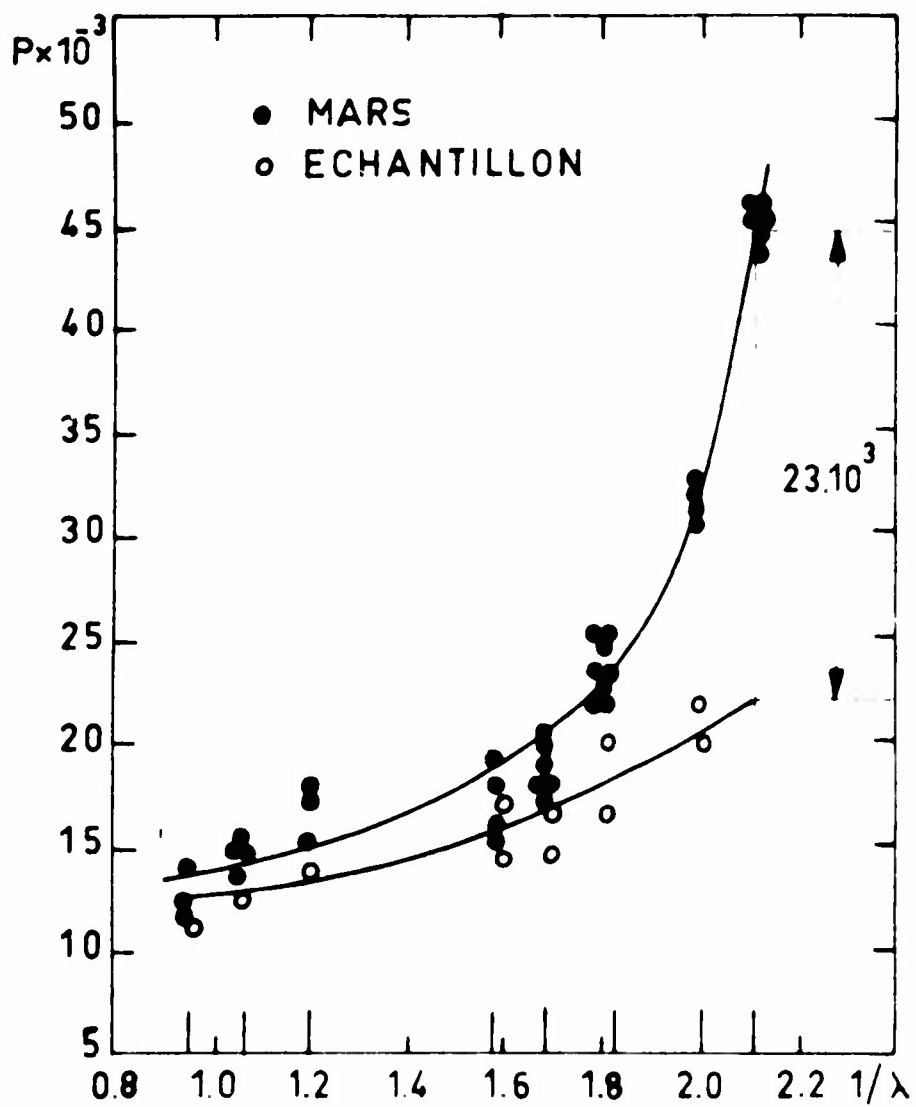
$B_a(\lambda, V)$  and  $B_s(\lambda, V)$  are the luminances of the atmosphere and the soil at the center of the disc. Calculations analogous to those developed above give :

$$\Delta P = \frac{B_a(\lambda, V=0^{\circ})}{B_s(\lambda, V)} \frac{\sin^2 V}{2} \frac{B_a(\lambda=0.47 \text{ micron}, V=0^{\circ})}{B_s(\lambda=0.47 \text{ micron}, V=39^{\circ}28')} \frac{2\Delta P}{0.410} = 0.110$$

The luminance  $B_s$  of the soil for the wavelength 0.47 micron for the phase angle  $39^{\circ}28'$ , can be determined from the photometric measures collected by A. DOLLFUS in 1950 and 1952 (30 ). At zero phase, at the center of the disc,  $B_s(\lambda = 0.47 \text{ micron}, V = 0^{\circ}) = 0.080$  times the luminance of a perfect scatterer; for the phase angle  $V = 29^{\circ}22'$ , we found 0.065; and extrapolation for  $V = 39^{\circ}26'$  gives 0.06 approx. for the sub-solar point and approx. 0.05 for the center of the disc, corresponding to a luminance of 0.08 stilb at 1.52 A.U. from the Sun.

Therefore, the luminance  $B_a(0,0)$  of the atmosphere of the planet at zero phase, at the center of the disc, for  $\lambda = 0.47$  micron, amounts to  $0.11 \times 0.08 = 8.8 \times 10^{-3}$  stilb at 1.52 A.U. and gives a scattering coefficient of about :

$$K_a(0.47 \text{ micron}) = 15.10^{-4} \text{ stilb/phot.}$$





RESIDUAL POLLUTION OF THE ATMOSPHERE OF MARS :

We have found for the red :

$$K_a(0.61 \text{ micron}) = 6,0 \cdot 10^{-4} \text{ stilb/phot.}$$

If the atmosphere of Mars, free from discernible aerosols, scatters as the molecules of a pure gas,  $K_a$  should vary inversely as the fourth power of the wavelength and give :

$$K_a(0.47 \text{ micron}) = K_a(0.61 \text{ micron}) \cdot 0.61^4 = 17,5 \cdot 10^{-4} \text{ stilb/phot.}$$

There is but a slight discrepancy between this value and that obtained here above, viz,  $15 \cdot 10^{-4}$ . Consequently, in the regions where the Martian atmosphere seems to be pure, there cannot remain appreciable quantities of aerosols scattering the light in a very different way than molecules, like particles having a diameter larger than the wavelength of the light.

Nevertheless, particles having a diameter much smaller than the wavelength increase the scattering power of the air but polarize about as much as the molecules; they could escape our analysis. If this is the case, the atmospheric pressure of 30 millibars, corresponding to the luminance observed at  $\lambda = 0.61 \text{ micron}$ , should be considered too high.

The new determinations of the atmospheric pressure by spectroscopy (31)(32)(33) or by the spacecraft Mariner IV (34) give lower values, between 9 and 20 millibars. If such is the case, the Martian atmosphere should contain permanently a small quantity of aerosols of diameters smaller than the wavelength, scattering light as molecules, and increasing the scattering power of the air to a ratio between 0.5 to 5 times its proper luminance.



TRANSPARENCY OF THE MARTIAN ATMOSPHERE IN THE BLUE :

The dark areas of the soil of Mars disappear almost completely in the blue and the violet; this has often been attributed to the strong absorption caused by a hypothetical, permanent blue veil in the atmosphere of Mars.

Though the values above established for the blue light :

$$B_a(V = 0^\circ) = 0.110 \times B_s(V = 39^\circ 8') \text{ and, on the other hand : } B_s(V=39^\circ 8') = \frac{0.05}{0.08} = B_s(V=0^\circ).$$

Therefore, the luminance  $B_a$  of the atmosphere amounts, for the phase angle zero, to  $0.11 \times \frac{0.05}{0.08} = 0.07$  times the luminance of the soil only.

This 7 % amount of light, coming from the atmosphere, is too weak to screen the dark features of the surface of Mars efficiently and make them disappear; the dark markings vanish in the blue, because the reflecting powers of the bright and dark areas of Mars, in this spectral domain, are very close. Consequently, due to the very low contrast between the said areas, the presence of even very faint additional atmospheric veils is sufficient to efface completely the surface markings. For instance, the so called "blue" clouds, observed almost permanently at the rising and setting limbs and often in other areas of the disc ~~can~~ mask completely details of the soil; concentrations of aerosols, of minor importance in view of the very low contrast between bright and dark areas, can produce this effect. The more rare "yellow veils", even very thin ones, consisting of flying dust, can equally completely mask the markings of the soil in blue light (5).

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